

UPGRADING EXISTING TERN ROAD TUNNELS TO CURRENT NEEDS, TAKING THE ARLBERGTUNNEL AS AN EXAMPLE

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ABSTRACT

The operation and safety facilities of European road tunnels in the Trans-European Road Network (TERN) must meet the requirements of Directive 2004/54/EC by not later than April 2019. This regulation applies to all tunnels in the TERN with a length of more than 500 metres, whether they are in operation, under construction or under design. This directive aims at ensuring a minimum level of safety for road users by preventing events which might endanger human life, the environment and tunnel installations. Taking the Arlberg road tunnel as an example, this paper shows how an existing road tunnel may be upgraded to meet the requirements of Directive 2004/54/EC and the Austrian national guidelines RVS. The Arlberg road tunnel is the longest single-tube road tunnel in Austria, and has a relatively low traffic volume. Hence, the construction of a second tube is not really cost effective. As this tunnel is the only winter-safe link between Tyrol and Vorarlberg, the closure of the tunnel during winter needs to be avoided as far as possible.

Keywords: TERN, egress ways, operation and safety facilities, FFFS

1. INTRODUCTION

The Arlberg road tunnel, with a length of about 15.5 km, is the longest single-tube road tunnel with bi-directional traffic in Austria. The tunnel connects St. Anton in Tyrol and Langen in Vorarlberg and is the only winter-safe link between Tyrol and Vorarlberg in the Trans-European Road Network (TERN).

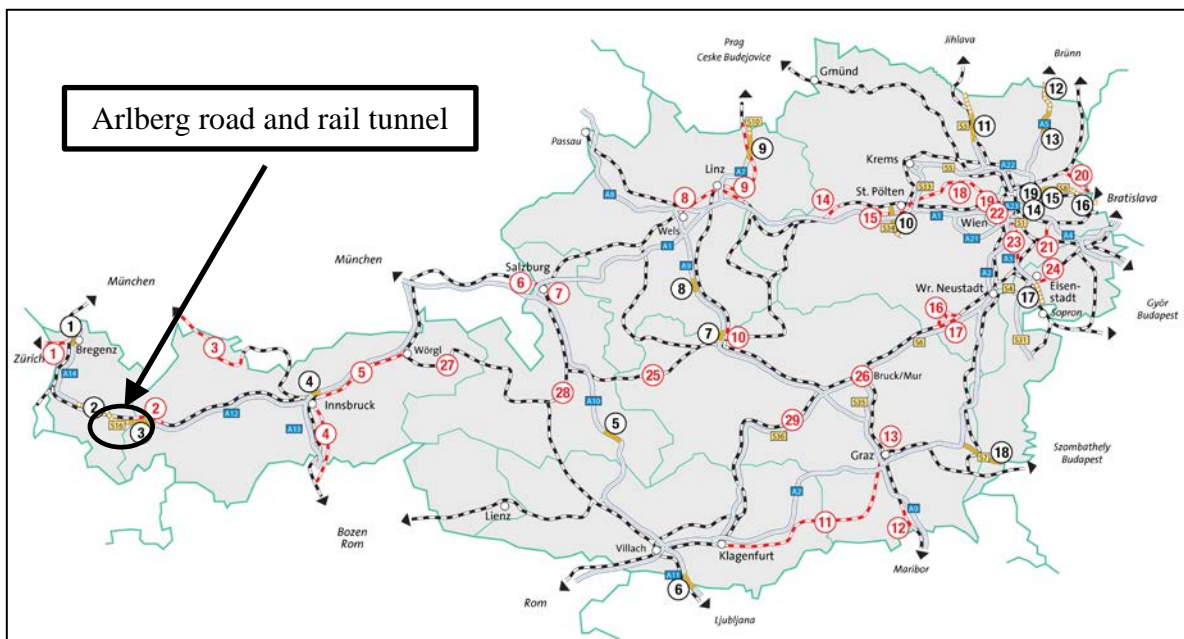



Figure 1: Location of the Arlberg road tunnel in the TERN (bm ).

The average daily traffic volume is about 8,000 vehicles/day. The peak traffic in holiday seasons is almost twice as high. The tunnel is equipped with a full transverse ventilation system with six ventilation sections, two vertical shafts (736 m and 218 m) and two portal stations. Each section is currently ventilated by one fresh and one exhaust air fan. Figure 2 depicts the ventilation scheme, where VS1 to VS6 denote the ventilation sections, F1 to F6 and E1 to E6, denote the fresh and the exhaust air fans.

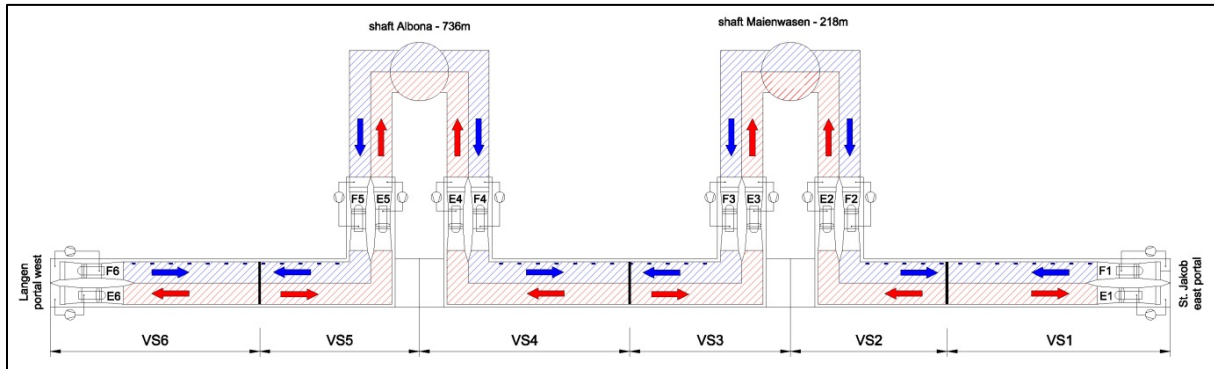


Figure 2: Sketch of the existing ventilation scheme of the Arlberg tunnel.

After 35 years in operation the Arlberg road tunnel needs to be refurbished. All the operation and safety facilities such as ventilation control system, video surveillance, alarm and radio equipment, fire detection, the road drainage and the fire-fighting water pipes need to be upgraded. In addition, 37 egress ways must be built in order to make the tunnel even safer for the road users.

In addition to the required structural refurbishment and the requirements of the RVS (Austrian guideline) [2] and the EU directive [1], the status of the existing operation and safety facilities was also investigated in order to ascertain the complete scope of refurbishment required.

Arlberg tunnel is part of the TERN. According to the EU directive [1] the distance between egress ways has to be reduced to a maximum of 500 m. The current escape galleries, which lead to the parallel railway tunnel, are located every 1,700m. An example of an existing egress way is shown in figure 3.

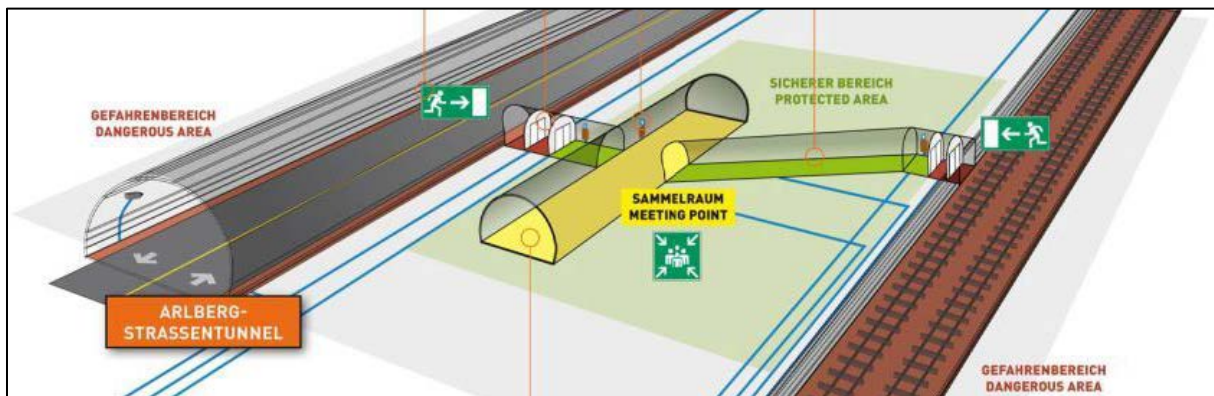


Figure 3: Example of an egress way in Arlberg road tunnel (ASIFI/NAG).

In the course of the design process, different options were examined in order to assess which of them might best meet today's requirements. The investigation included the development and comparison of an optimized procedure with respect to construction work and site logistics, traffic operational, loss of toll income, possible traffic routing and, last but not least, construction costs.

As the distance between railway and road tunnel is never more than 300 m there is no need for further escape routes for the railway tunnel. Thus, instead of introducing further cross passages to the rail tunnel of the following solution was chosen. In future, the fresh air ducts between the existing cross passages to the railway tunnel will serve as egress ways. While this minimises construction costs, it does require additional installations for maintaining egress user safety. Figure 4 shows a sketch of the road and railway tunnel, as well as of the existing and the new egress ways.

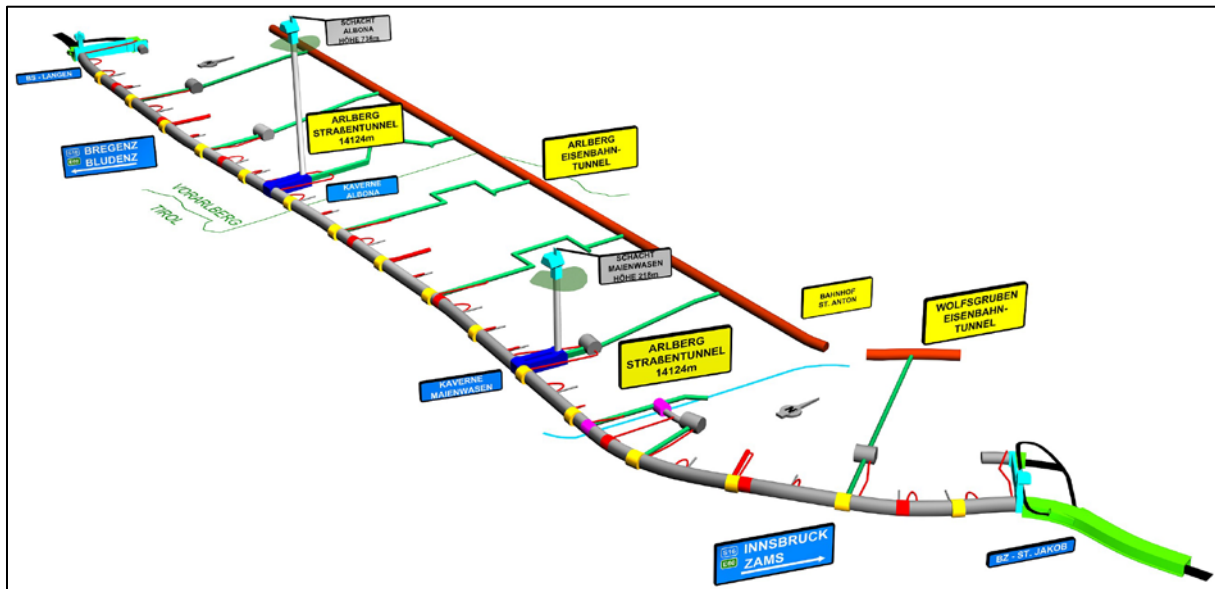


Figure 4: Sketch of the egress ways of the Arlberg tunnel (© AISFINAG).

2. FEASIBILITY STUDY

In order to fulfil the relevant regulations and to find a practicable design, a feasibility study was performed. The following options were investigated:

- option 1: Total closure of the Arlberg road tunnel for the whole period of refurbishment
- option 2: Ongoing traffic operation with short closures only at certain times (e.g. night time), together with some unavoidable closures over a few days.
- option 3: Seasonal closures from the middle of April to the end of October together with convoy control during the night.
- option 4: Construction of a new single tube, with the existing tube being used as escape and rescue tunnel
- option 5: Construction of a second tube and refurbishment of the existing tunnel

2.1. Results - Assessment of the construction time

In order to keep traffic restrictions to a minimum, the refurbishment of the tunnel and further lining of the egress ways must be carried out in several temporally distinct phases. Figure 5 shows the predicted construction times of the five options.

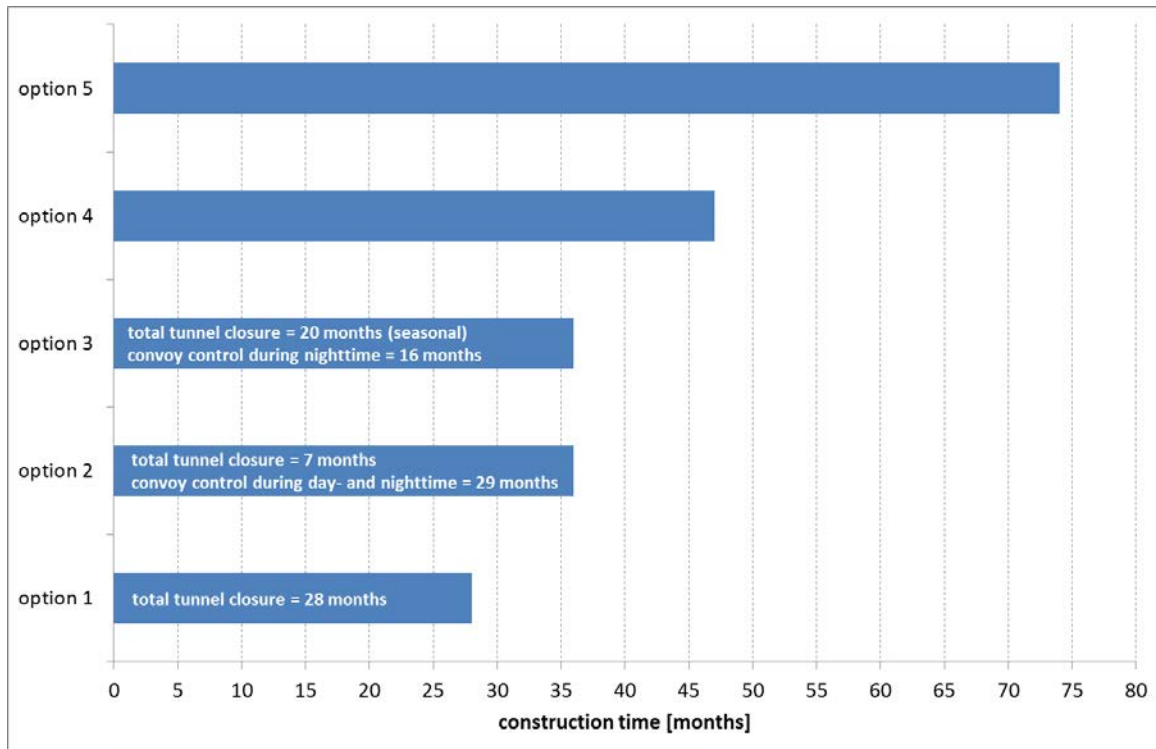


Figure 5: Construction times.

In option 3 the refurbishment of the existing tunnels will take place in 3 seasonal closures between April and the end of October. Thus, compared to option 1, the Arlberg road tunnel can be used during wintertime and the traffic burden in the city of St. Anton can be substantially reduced.

2.2. Results - Assessment of the technical and economic feasibility

Option 2:

Option 2 can not be recommended from an economic and technical point of view. This is largely due to concerns relating to tunnel user and construction worker safety as a lot of work must be done within in the traffic room.

Option 4:

Option 4 was acceptable in terms of technical and safety considerations. However, compliance with the RVS and the STSG would make a larger cross-section and larger breakdown bays necessary in the new tube. This would lead to significantly higher additional costs in the coming decade. In fact, the overall costs of option 4 are more than twice those of option 1 and 3. Even though traffic flow would still be possible during the whole construction period, the toll income gained would not be sufficient to compensate for the extra cost. Hence, option 4 can not be recommended from an economic point of view.

Option 5:

Option 5 represents the safest option for the tunnel users and is also acceptable in terms of technical considerations. In terms of economics, however, this is the most expensive option. The overall costs of option 5 are more than 2.5 times higher than the costs of option 1 and 3.

Option 1 & 3:

From the economic and technical point of view option 1 (total closure) is to be preferred to option 3 (seasonal closure). Seasonal closures entail lower additional costs and lower revenue loss as no provisional arrangements or multiple treatments are necessary. The construction work can also be handled with appropriate quality. The difference in the relative costs of the two options is in the range of about 10 percent.

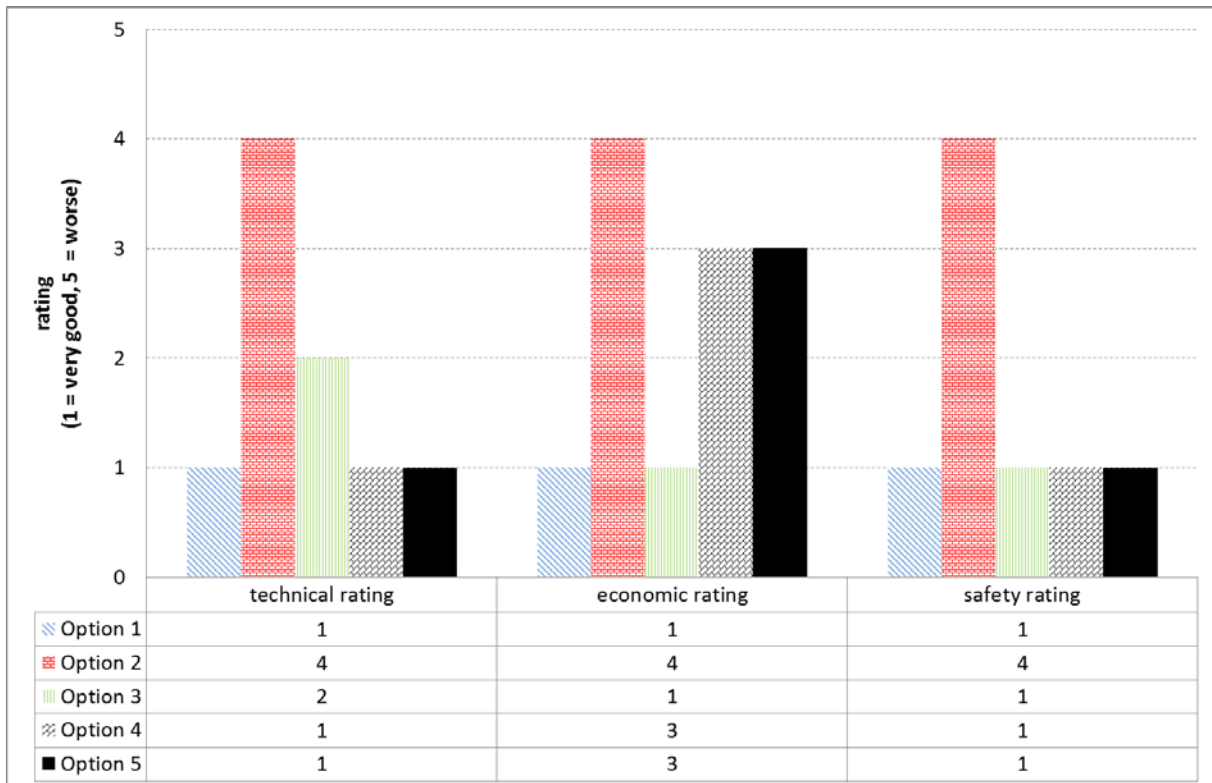


Figure 6: Rating of the five different options.

Based on the results of the feasibility study, option 3 was selected for realisation.

3. DETAILED DESIGN

3.1. Operation and Safety Facilities

Fixed Fire Fighting System (FFFS)

A FFFS will be installed throughout the tunnel. An FFFS has the potential to reduce the rates of fire growth and fire spread. In the event of a fire, this helps tunnel users and emergency services during the self-rescue phase. Other potential benefits of an FFFS are protection of tunnel assets from fire damage, and minimisation of road network interruptions during post-fire repairs.

Storage niches and break-down bays

Break-down bays and storage niches are located every 1,000 m, and provide safe parking spaces.

Audio tunnel monitoring (AKUT)

Microphones transmit data to a special database. Special software is able to differentiate between the normal sound of the traffic and unusual noises such as collisions or screeching tyres and brakes. Any alarm automatically activates the camera nearest to the sounds so that the staff in the control centre can respond immediately.

Impact absorbers

In cases of collision, impact absorbers serve to reduce the accident severity of vehicles or to direct vehicles back onto the traffic lane.

Energy

In cases of emergency, the tunnel has an autonomous energy supply (transformers, emergency generators).

Fire extinguisher points

Fire extinguisher points containing a hydrant are installed every 125m to 150 m.

High-tech tunnel monitoring

A range of high-tech systems such as video image evaluation and fire detectors ensure rapid response to any accident. The opening of doors is monitored via the use of door contacts. Emergency signals – SOS or fire – can be activated by manual and automatic alarm.

Information systems

To ensure that drivers are kept fully informed about traffic conditions a range of information systems such as loudspeakers, information boards, radio announcements and signs are available.

Intelligent light systems

Brightness sensors ensure that optimum lighting is available to drivers at all times. The brighter it is outside the tunnel, the brighter it will be in the entrance portal zone. This makes it easier for tunnel users to adapt to the illumination level.

Emergency phone systems

Emergency phones with illuminated compartments are located approximately every 125 m in the tunnels.

Traffic

The tunnel is fitted with CCTV which transmits images to the tunnel control centre. Sensors in the tunnels provide additional information on traffic levels, visibility or air conditions. In the event of a disruption, traffic can be quickly and adequately managed by the tunnel operators. All HGVs and buses over 7.5 tonnes maximum permissible weight (MPW) pass through the thermal scanner on a dedicated lane before entering the tunnel. The system measures the outer skin of the vehicle using laser scanners in order to create a 3D image. Two infrared cameras additionally record the temperature from both sides. Critical points, such as tyres, wheel bearings, the engine area and exhaust systems are precisely localised. Special software combines and analyses all the data. In the event of overheating, the vehicle is taken off the track to cool down or to allow for troubleshooting. After the problem has been dealt with it is returned to the thermal portal.

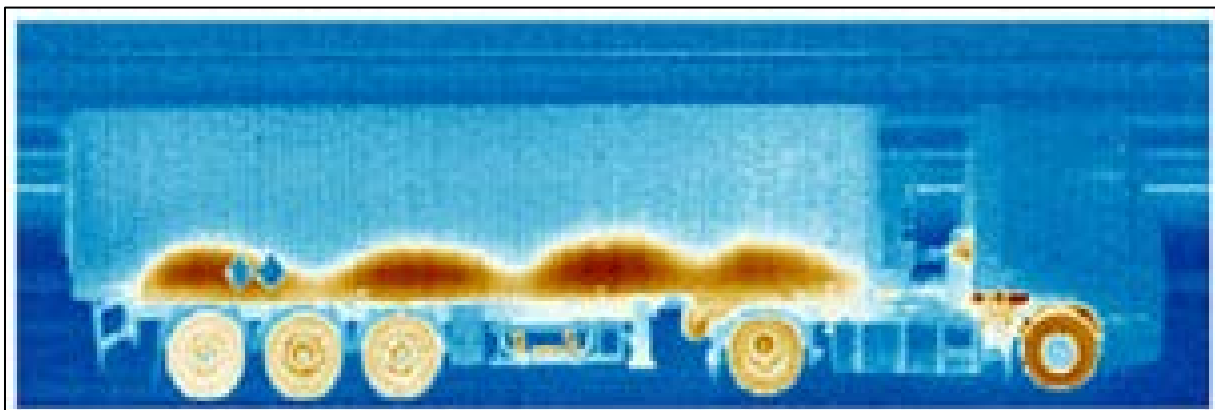


Figure 7: Thermal imaging cameras - external temperature of the vehicle (ASFINAG).

3.2. Egress ways

As described above the distance between railway and road tunnel is quite large. In order to minimize construction costs it was decided that the fresh air ducts be used as egress ways. To enable handicapped people to use the egress ways, instead of stairways, ramps with a gradient not exceeding 10% will be constructed. Figures 8 and 9 depict the new egress ways.

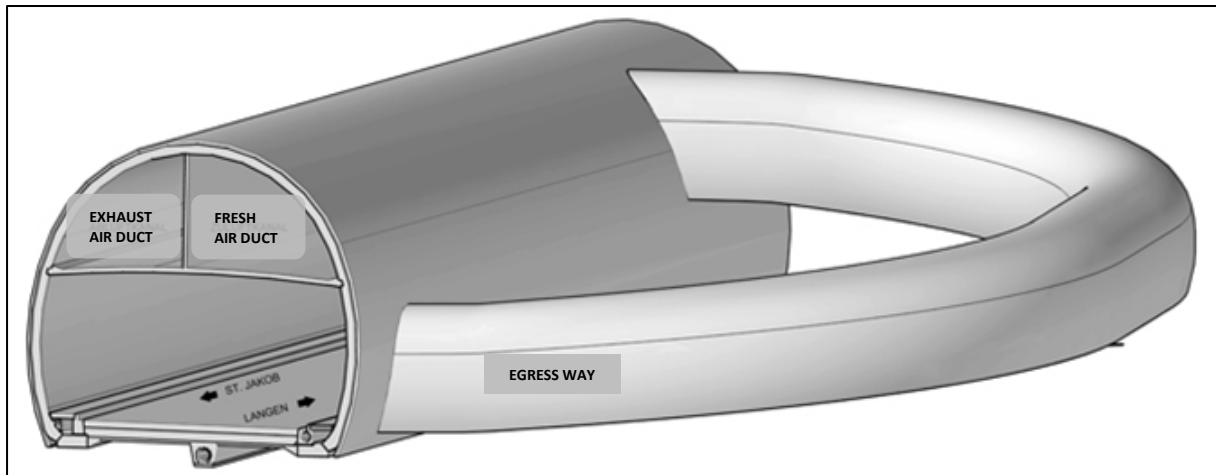


Figure 8: Scheme of the new egress way (ASFINAG).

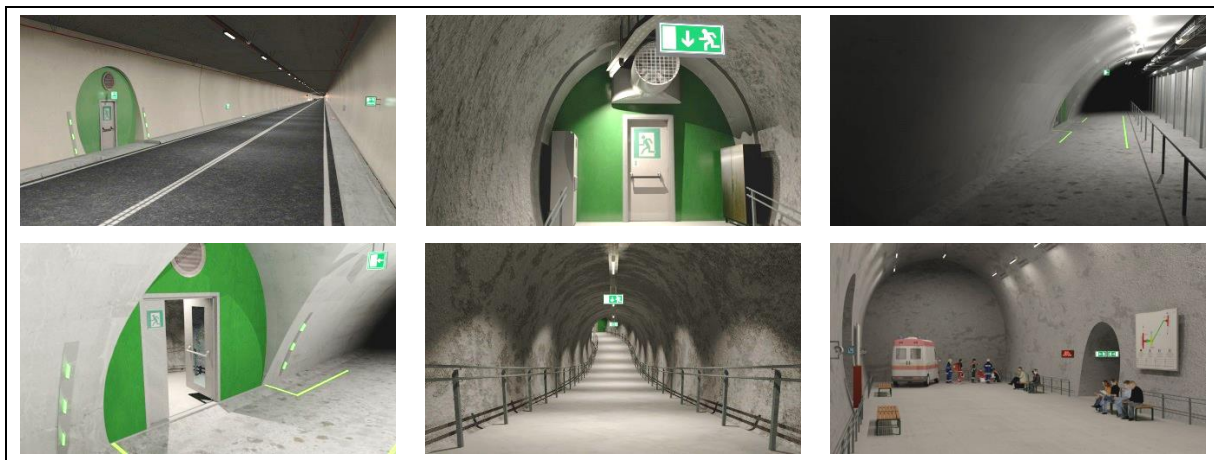


Figure 9: Images of the new egress ways (ASFINAG).

3.3. Fire ventilation

The main issue in fire ventilation lies in the problem of confining smoke to the region of the extraction damper. As the Arlberg tunnel represents a weather barrier the meteorological pressure differences between the two portals are quite high. They amount to 254 Pa, the 95th percentile of the half-hour mean values of the pressure differences. Hence massive electro-mechanical installations in the form of jet fans or air injection nozzles are needed in order to maintain pressure gradients. A cost-benefit analysis indicated that usage of the existing fresh air fans for air injection is appropriate. This requires the installation of fresh air injection dampers (FAID) and sealing doors within the fresh air duct. Figure 10 depicts the scheme of the upgraded ventilation system with the FAIDs and additional jet fans (JF1 to JF3) for smoke control. Figure 11 depicts the cross-section of the tunnel at the place of the jet-fans. The advantage of this system is that existing fans can be used and structural adaptations inside the tunnel can be reduced to a minimum. The drawback of FAIDs is that each additional device raises the flow of air into the tunnel. The increase in momentum (thrust) brought into the tunnel is accompanied by an increase of the volume flow rate. Hence the air/smoke velocity inside the tunnel also increases. Use of a simple jet fan, in contrast, would only produce the required thrust in the traffic room. In order to overcome the problem of increasing volume flow rates, air extraction in other ventilation sections has to be utilised to achieve the required pressure balance (push – pull system). Such a concept was originally implemented in Austria in 2002, using a full closed loop control system for the 10 km long Plabutsch tunnel [3]. At that time, however, vertical air injection and extraction was employed without using the

momentum of the injected air. Systems with FAIDs have since been applied successfully in Austria in several long road tunnels [4]. What is new in the Arlberg tunnel, is the parallel usage of multiple FAIDs and jet fans as well as air extraction in sections other than in the fire section.

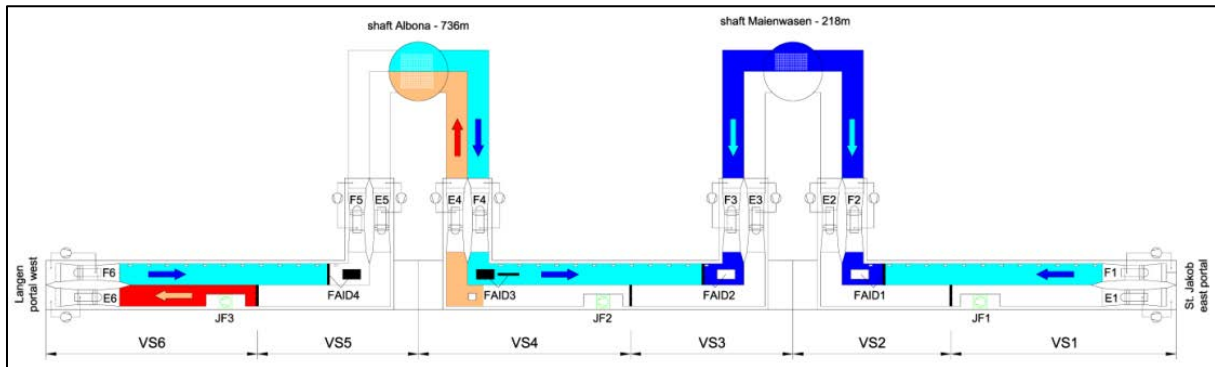


Figure 10: Sketch of the new ventilation scheme of the Arlberg tunnel.

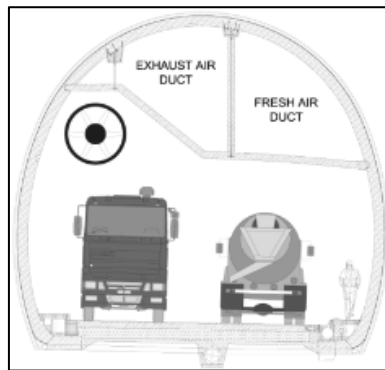


Figure 11: Sketch of the cross section in the region of jet fan JF1/2/3.

Figure 12 shows a scenario for a 30 MW fire in ventilation section VS6. Close to the fire location a mass flow of 144 kg/s smoke/air is to be extracted. In order to achieve a nearly symmetrical flow from both portals towards the extraction location the usage of the FAID 1 and FAID 2 as well as of the jet fans JF1 and JF2 is needed. In addition air extraction is required in section VS6. In this particular case, various exhaust air and fresh air supply fans as well as the jet fans are needed at the same time in order to reach the required ventilation goal. The remaining fresh air fans are needed to vent the escape route via the fresh air duct. Figure 13 shows the velocity distribution inside the tunnel resulting from fan activation in this scenario. As can be seen, symmetrical air flow from both sides of the incident location towards the extraction point can be achieved.

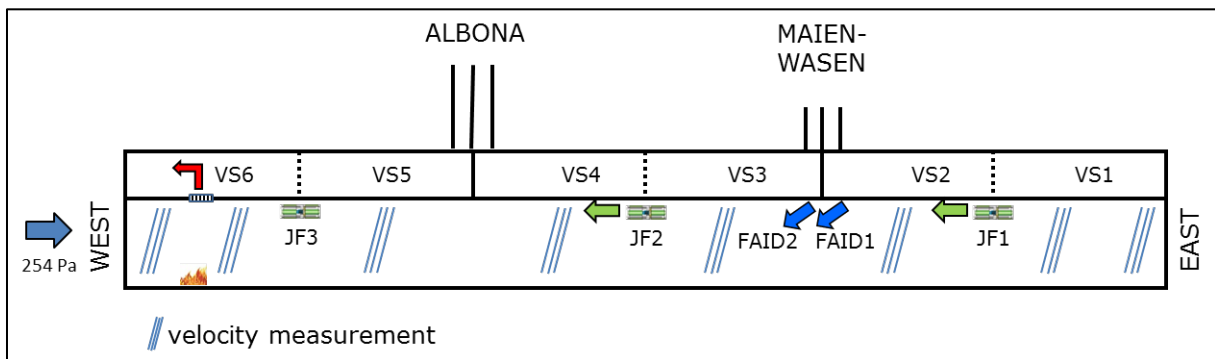


Figure 12: Fire ventilation for an incident in ventilation section VS6.

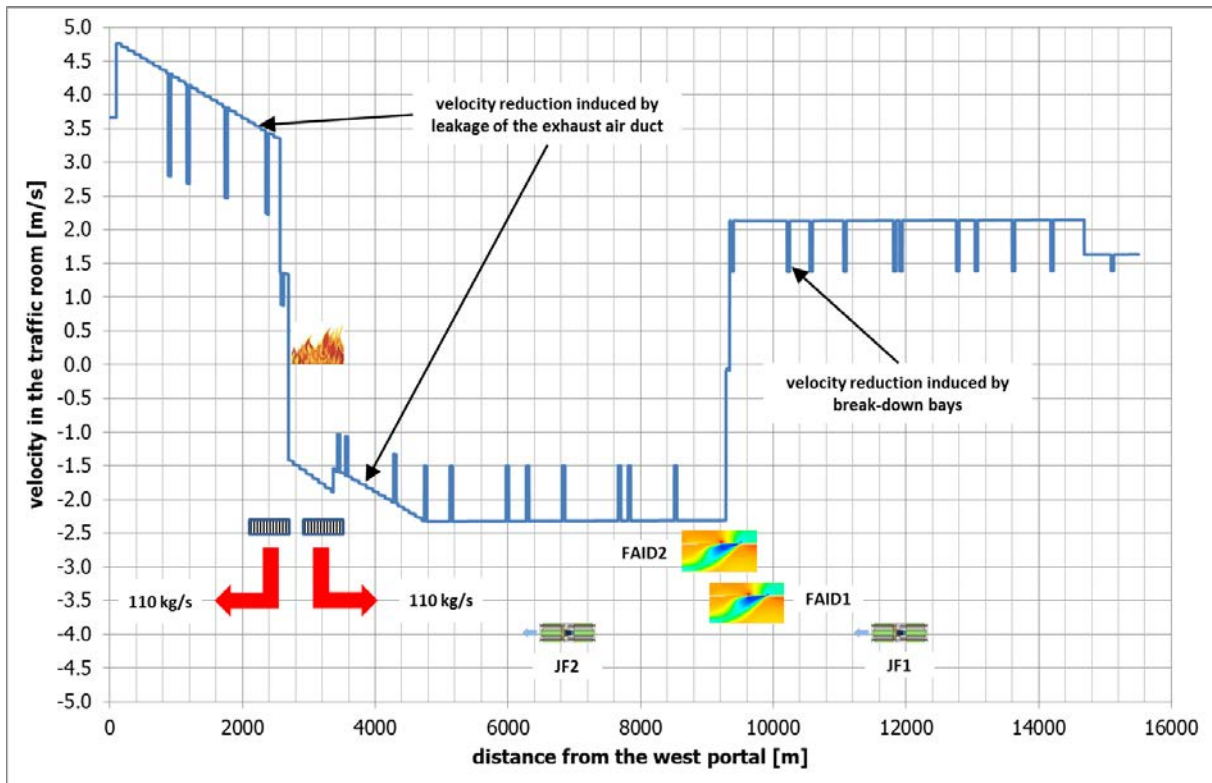


Figure 13: Air velocity distribution for an incident in ventilation section VS6.

The ventilation system chosen for the Arlberg tunnel utilises as much existing equipment as possible and thus helps avoid new construction of major civil works that would otherwise be necessary in order to achieve current safety requirements. It represents a compromise between the requirements of cost efficiency, the time available for system refurbishing and upgrading, and technical feasibility. The tunnel is quite long, hence the air masses that need to be moved in the case of a fire are relatively large. As a result of the high level of inertia, the control behaviour of the flow is expected to be relatively slow. However, the equipment available to control the velocity inside the tunnel (FAID and air extraction) is powerful enough to cope. Sufficient time for adjusting the software parameters as well as for testing the whole system will be required. This has to be followed by a dense schedule of system tests in order to minimise the risks of producing an overly complex, or unwieldy ventilation system.

3.4. Structural fire protection – fixed fire fighting systems

To protect the intermediate ceiling - and thus the fresh air duct which serves as an emergency escape - against high temperatures a high pressure water mist system will be installed in the traffic room of the Arlberg road tunnel. Aqueous Film Forming Foam (AFFF) is used to coat fuel, preventing its contact with oxygen, and thus resulting in suppression of combustion. The high pressure water mist system enables the water mist to penetrate into a fire in liquid form and result in cooling due to evaporation at specific locations. High pressure water mist also effectively fills up the protected space and provides superior cooling, hence protecting surrounding equipment and structures.

Design parameters for the FFFS:

- Liquid pool fire: 200 MW
- Operation time: 120 Minutes
- Aqueous Film Forming Foam: 1 % - 3 %
- Basic design parameters: RVS 09.01.45 [5] and RVS 09.02.51 [6]

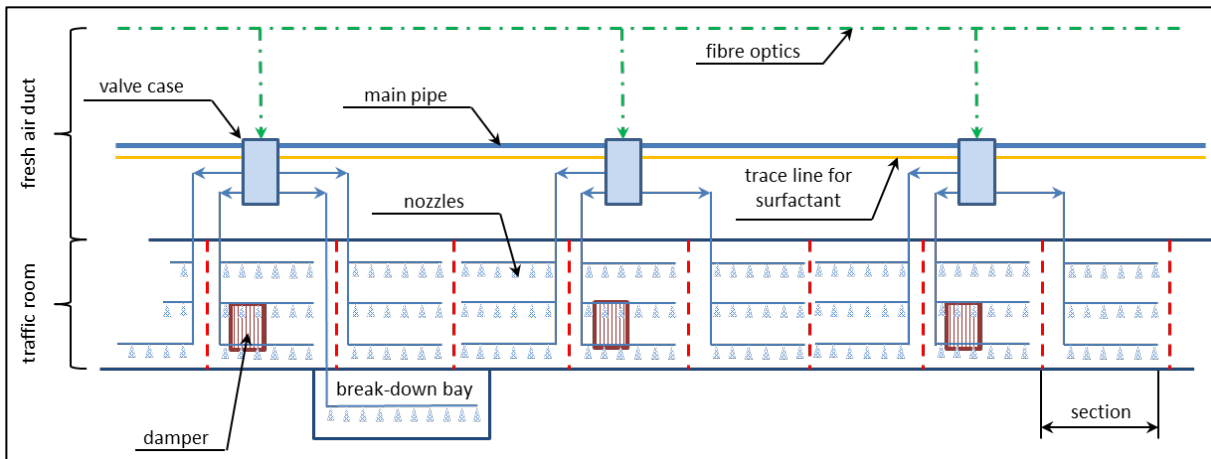


Figure 14: Scheme of the high pressure water mist system.

4. CONCLUSION

The Arlberg road tunnel will be refurbished within the period autumn 2014 to autumn 2017. A feasibility study including 5 options for upgrading the tunnel was performed. The feasibility study showed that the construction of a second tube for unidirectional traffic (option 5) or the construction of a new bi-directional tube - using the existing tube as escape and rescue tunnel (option 4) - is not suitable due to the low traffic volume and the length of the tunnel. Option 1 requires too many tunnel closures and the loss of toll income is too high. Option 2 was not found to be acceptable due to the high safety risks arising during the construction time.

Therefore option 3 was selected for realisation. This option has a relatively short construction time and is also to be recommended from an economic and technical point of view.

The Arlberg road tunnel has a full transverse ventilation system. In order to minimize construction costs the fresh air duct will be used as an egress way. Construction of long cross-passages to the parallel railway tunnel can thus be avoided. In the case of fire tunnel users can reach the fresh air duct (safe area) via ramps from the traffic room. From the fresh air duct the egress ways lead to existing collecting rooms, from where the tunnel users can be evacuated through the railway tunnel.

In order to protect the fresh air duct against high temperature, fixed fire fighting systems will be installed in the traffic room. In addition, complete replacement of all the safety equipment is to be carried out.

5. REFERENCES

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