TECHNICAL EQUIPMENT OF TUNNELS FOR DRAINAGE AND FIRE PREVENTION DEMONSTRATED BY THE EXAMPLE “EISENBAHNACHSE BRENNER, ZULAUFSTRECKE NORD”

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ABSTRACT
At present the „Eisenbahnachse Brenner“ from Munich to Verona is partly re-designed. One section is an about 40 km long line in the Inntal north of the Brenner. This line mainly follows the existing double-tracked location line from Kufstein to Innsbruck. However, on account of the fact that the area is densely populated it must switch to tunnel lines and covered troughs. Therefore a high percentage of tunnel constructions is planned. The necessary safety facilities like emergency routes and location line draw downs into the groundwater area require a great deal of technical expenditure compared to designs of the first generation in railroad tunnel construction.

This is why the lecture will deal with design principles of pumping stations, maintenance basins, safety facilities for tunnels and life-saving tunnels in case of fire.

Keywords: pumping stations, life-saving elevators, backlayering, aeration, fire protection sluices

1. PUMPING STATIONS
1.1. Waters and liquids to be pumped off

1.1.1. Groundwater
Tunnels and groundwater troughs of railroad constructions are made in a leak proof way or leak proof to a high extent. According to water right law this is an indispensable general demand. Otherwise there will be an important interference with groundwater balance. Hence, the greatest part of groundwater is mountain water provided that a drainage in the mountains does not have any detrimental effect on the general water balance. Therefore the amount of water of such origin can be regarded as negligible.

1.1.2. Rain-water
Contrary to groundwater, rain-water in open troughs and rain-water on trains in portal areas of tunnels are an important source. The amount depends on the respective local peak rain loads and on the size of the trough area/catchment area. In alpine regions a rain load of more than 15 minutes with an intensity of 300 to 330 l/s. hectare is to be expected.

1.1.3. Liquids due to accidents and leakages
The compounds of such liquids and the resulting hazardous potential can vary tremendously. Therefore increased precautions have to be taken in order to avoid explosions or other dangers to health. The amount resulting from one single accident at least corresponds with the volume of a big tanker or 108 m³. Even pumping stations for rainwater may be affected by such an accident. Therefore the necessary precautions also have to be taken with such pumping stations.
1.2. Pumping stations for rain-water

When dimensioning and designing the pumping stations it is not the economic aspect that should dominate the design, because the running time of the pumping station will be very short except when mountain water is pumped off. The aspects that should mainly be considered are safety in operation and low maintenance costs.

For safety in case of accident a big open ball passage, the bilateral power supply, the redundant design of the control system and a 100% reserve of the pump efficiency are absolutely indispensable. As for short pressure pipelines, a separated realisation for each pump as far as the gravitational flow into receiving body of water is suggested because therewith the wear and tear of fittings, reflux valves, slide gates and pipe fittings is avoided. Frequency converters for adapting pump efficiency to influent amount can and shall be dispensed with. Instead of that the volume of the suction well shall be set to a maximum switch. This is different when mountain water is pumped off because its constant yield necessitates an economic pump capacity.

The dimensioning of the suction well volume is based on the simple function. It may also be shown in a diagram. For the switch frequencies \( n = 8 \) times per hour the functions are marked.

\[
n = 1 \left( \frac{V}{Z} + \frac{V}{P-Z} \right)
\]

\[
V = \text{volume}
\]

\[
i = \text{inflow}
\]

\[
P = \text{pump-capacity}
\]

**Figure 1:** Suction well volume:

In case of accident suction wells may be regarded as high explosive areas because easily inflammable liquids may also flow into the suction well. Due to the possibility that the liquids may contain concrete corroding substances suction wells have to be protected by an acid proof and alkali proof surface cover. As for pumping stations in buildings e.g. in life-saving stairwells, a separation of suction well and pump room is suggested because therewith the pumps may be maintained in a dry room and there is no contact with the medium during maintenance. It is suggested that these pumps are submerged pumps as well in order to have additional safety in case of flood.

Preferably, pumping stations which may be maintained from site should also be submerged pumps with duck feet and draw down facility.
1.3. Maintenance basin

In case of accident in a tunnel the liquids from tankers are directed to the maintenance basins, which are situated at the lowest point of tunnel constructions. In some cases such basins are included in the plan (underneath the life-saving tunnels). These basins with about 108 m³ of effective volume are explosive areas. They are not equipped with stationary pumps. Via sluice pipes probes may be taken, chemicals for precipitation, neutralisation or prevention of explosive atmosphere may be added. After definition or neutralisation of the liquid the liquids shall be disposed via the stationary installed suck and pressure pipes by means of portable chemistry pumps. In order to protect buildings against explosion, explosion relief shafts with large cross-sections reaching beyond the ground surface are planned.

2. SAFETY FACILITIES

2.1. Definition of safety standard

The kind and scope of architectural and operational precautions for the self-rescue of travellers and railroad staff as well as the action of assistants and rescue parties are defined in the guideline on “Construction and Operation of New Railroad Tunnels Concerning Main and Side Lines” of the Austrian Professional Fire Brigade Union (ÖBFV-RL A –12). More or less these guidelines define the state of the art in technology and have to be regarded as the basis for the authorization procedure of railroad constructions.

As for road tunnels these guidelines correspond with the guideline for safety in traffic RVS 9.261.

In the ÖBFV – RL a safety concept is demanded as a presupposition for any authorization. This concept defines the qualifications of the rescue party; the presupposition for self-rescue and rescue of others in the area of the tunnel, for the safe areas – emergency stairwells, life-saving tunnels, sluices etc. In the following the required freight elevators and the standards of escape route sluices as well as their aeration and the foundations will be dealt with.

2.2. Freight elevators

According to the ÖBFV-RL emergency stairwells with a difference in altitude of up to 30 m have to be equipped with a loading rack with a mobile electric elevator for the transport of heavy equipment and injured persons. The authorization basis to be applied for the transport of injured persons as well as the rescue party is the working device decree (BGBl. II Nr. 164/2000) because the elevator will only be operated under supervision and/or instruction. In this specific case the size of the elevator cage has to be 1,50 x 2,00 m.

![Figure 2: Example of a pumping station in a life-saving stairwell](image-url)
Among other things the decree mentioned above provides that elevator cages are compact, doors are locked automatically, and that the transport area is compact in order to prevent injuries in the stairwell.

2.3. Rescue and aeration concept in case of fire in a tunnel

As for the railroad tunnel with on-coming traffic the rescue or aeration concept respectively differs very much from that of a motorway. In a long motorway tunnel with on-coming traffic it is tried to suck off the fumes in the traffic area and therewith keep this area as a non-toxic escape route. In contrast to that a railroad tunnel is not aerated.

It must be possible to reach safe areas in the railroad tunnel within a distance of about 250 m. These safe areas are either life-saving tunnels or sluiceways to emergency stairwells. The sluiceways must be at least 12 m long.

In case of fire sluices have to be aerated in a way that even if both sluice gates are open, an excess pressure of such power is produced that an intrusion of fumes into the safe area is prevented.

Adjacent to the sluices an area of at least 25 m² has to be provided as an intermediate place to stay.

This area can be dispensed with when even physically handicapped people are able to exit into the open without difficulties.

Life-saving tunnels may be 150 m at the very most if they do not lead directly into the open but only do so via emergency stairwells. Life-saving tunnels which are longer than 150 m must be passable by road or rail vehicles.

When designing emergency stairwells the limited physical ability of infirm or physically handicapped people have been taken into account adequately.

2.4. Aeration facilities

2.4.1. Necessary fresh-air volume in case of fire

The aeration of sluiceways is only intended for the case that fire breaks out and the train cannot leave the tunnel for technical reasons any more. The people escaping from the traffic tunnel should be safe when they reach the aerated sluice.

While the calculation of the necessary fresh-air volume in a road tunnel is based on the exhaust fumes and the pollutant concentration limit in the tunnel, the fresh-air volume in railroad tunnel cannot be calculated in that way because in train traffic there are no dangerous exhaust fumes.

When calculating the necessary fresh-air volume for escape routes it has to be assumed that both sluice gates are opened when a great number of people try to escape. In order to protect escape routes from even partly thickening with smoke (e.g. backlayering) air with the so-called critical velocity has to be blown against them. This critical velocity was calculated dependent of the fire size. Figure 3 shows the results of this calculation.

Taking a fire size of about 60 MW in consideration, the critical velocity u/m/s is defined as 3 m/s. With that the necessary fresh-air volume V (m³/s) can be calculated from the equation V = A. u when the escape tunnel cross section A (m²) is given.
2.4.2. Pressure ratios in railroad transport

When a train enters the main tunnel an overpressure is produced in front of the engine whereas a negative pressure is produced at the rear of the train. The train works like a piston in a cylinder, however it is not a very tight piston. The longitudinal velocity which is produced by the traffic in the main tunnel can be calculated according to the following equation:

\[
\frac{du_v}{dt} = -\frac{1}{2} \left( \frac{\lambda}{D} + \frac{1+\zeta}{L} \right) u_v^2 \text{sign}(u_v) + \frac{P_1(t) - P_2(t)}{\rho(t)L} + \\
+ \frac{A_1 c_w N_1}{2 L A_v} [v_1(t) - u_v]^2 \text{sign}(v_1(t) - u_v) + \\
+ \frac{A_2 c_w N_2}{2 L A_v} [v_2(t) - u_v]^2 \text{sign}(v_2(t) - u_v) + \frac{S(t)}{\rho(t)L A} \tag{2.2}
\]

Legend:

- \( s \) time
- \( \lambda \) pipe friction correction value in the main tunnel
- \( D \) hydraulic diameter of main tunnel
- \( \zeta \) entry loss correction value in main tunnel
- \( L \) length of main tunnel
- \( u_v \) m/s air velocity in main tunnel
- \( P_1 \) N/m\(^2\) meteorological and thermostatic pressure at gate 1
- \( P_2 \) N/m\(^2\) meteorological and thermostatic pressure at gate 2
- \( \rho \) kg/m\(^3\) density of air in tunnel
- \( A_1 c_w \) m\(^2\) mean resistance area of trains in the main tunnel that move from gate 1 to gate 2
- \( A_2 c_w \) m\(^2\) mean resistance area of trains in the main tunnel that move from gate 2 to gate 1
- \( N_1 \) number of trains in the main tunnel that move from gate 1 to gate 2

**Figure 3:** Air velocity for the prevention of backlayering

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$N_2$  number of trains in the main tunnel that move from gate 2 to gate 1

$m/s$  mean velocity of trains in the main tunnel that move from gate 1 to gate 2

$v_2$  $m/s$  mean velocity of trains in the main tunnel that move from gate 2 to gate 1

$A_v$  $m^2$  area of main tunnel

$S$  $N$  thrust in main tunnel

For the calculation of longitudinal velocities the resistance area of the trains must be given. This can be calculated according to /3/ by means of the values given in /4/. For further calculation it is supposed that $A_1 \cdot cw = A_2 \cdot cw = A \cdot cw$. In the given case this results in a value of $A \cdot cw 120 m^2$.

With the given equation the velocity as well as the pressure course can be calculated.

Figure 4 shows the velocity course in the 10,470 m long VOMP tunnel based on the supposition that there is no effective pressure difference between the 2 tunnel portals. The train enters the tunnel with a velocity of 250 km/h (69.45 m/s) at a time $s = 100$ sec. It is also supposed that the total resistance area ($A \cdot cw$) gets fully effective as early as the engine enters the tunnel. The total length of the train is reduced to zero in this calculation.

You can see that the longitudinal velocity of the air in the tunnel quickly rises to about 13.7 m/s. For an unhindered passage through the tunnel the train takes about 150 sec. After this the train leaves the tunnel again. When the engine leaves the tunnel it is assumed that the total resistance area immediately lapses. When the train has left the tunnel, the moving air gets slowed down by wall friction - at first very quickly, later more slowly. Only after about 10 min. the longitudinal velocity has slowed down to about 1 m/s.

\[ \text{Figure 4: Distribution of velocity in the main tunnel VOMP (} A \cdot cw = 120 m^2, \text{ train passes, pressure difference } p1-p2 = 0 N/m^2) \]

Figure 5 shows the static changes in pressure to be expected at a travel velocity of 250 km/h in the Vomp tunnel provided that there are no effective pressure differences between the 2 portals and that the engine has just passed 3,000 m in the tunnel. In front of the engine a strong overpressure is produced, at its rear an under-pressure is produced. The total pressure
difference is about 3,000 N/m³. In case that there are effective pressure differences, the final points of the diagram have different levels. However, this does not change anything in the principal pressure course.

Figure 5: Pressure course in the main tunnel VOMP during passage of a train (the train has just passed 3,000 m in the main tunnel)

Figure 6 shows the march of the calculated longitudinal velocity $u_v$ in the tunnel when a train moves through the tunnel from the left at a speed of 250 km/h. After 150" the train leaves the tunnel through the right gate. One minute later an oncoming train enters the right gate, moves through the train at constant velocity and also reaches the left gate after 150". First the longitudinal velocity $u_v$ in the tunnel increases and then reaches its highest value i.e. ca. 13 m/s just before the train leaves the tunnel. After this the longitudinal velocity decreases slowly. However, it is reversed when the oncoming train enters from the opposite direction and then it gets accelerated to ca. 13 m/s. After the exit through the left gate the longitudinal velocity decreases slowly and gets back to zero provided that there is no thermic-meteorological pressure difference between the gates.
The situation is similar when a train at high speed enters the tunnel through the left portal (km 0) and then slows down. 15 seconds after this an oncoming train reaches the right portal and enters the tunnel. Only in the tunnel the emergency brake is applied. On account of the oncoming train the longitudinal flow is turned around. When the oncoming train has stopped there is a longitudinal velocity ranging from about 4 m/s to 5 m/s in the tunnel.

The approximate pressure ratios in the tunnel for a longitudinal velocity of –4.5 m/s are shown in Figure 7. You can see that there may be an overpressure of about 250 N/m² at the rear of the oncoming train.

It is true that this value is high. However, it cannot be excluded completely that there is an overpressure in the main tunnel – even if only for a short time – when the fire alarm is released. Therefore this overpressure was also taken into account as a possible inflow pressure from the main tunnel when designing the axial blowers.

Figure 6: March of pressure with oncoming train
2.5. Dimensioning of blowers

The necessary pressure increase $\text{diff} \cdot p$, which is to be supplied by the respective axial blower, mainly consists of 3 parts:

- $\text{diff} \cdot p_{FD}$ (losses by friction, diversion etc.)
- $\text{diff} \cdot p_{Th}$ (thermic influences)
- $\text{diff} \cdot p_{TM}$ (influences by train movements in the main tunnel)

The efficiency of the blowers results from the equation:

$$P = \frac{V \cdot \text{diff} \cdot p_{T}}{\eta_V}$$

2.5.1

$V$ is the required air volume and $\text{diff} \cdot p_{T}$ the required total pressure increase.

$$\text{diff} \cdot p_{T} = \text{diff} \cdot p_{FD} + \text{diff} \cdot p_{Th} + \text{diff} \cdot p_{TM}$$

2.5.2

Normally, the efficiency of the blower total unit (BTU) is expected to be $\eta_V 0.7$

For stand-by reasons it is advantageous to use one or two blower sizes and to make the adjustments to the respective pressure ratios by different rotation speeds. As the blowers are only applied in an emergency, the reduction of efficiency does not play an important role.

2.6. Design of aeration facilities

2.6.1. Life-saving wells and life-saving tunnels

The demand to aerate the sluiceways in front of the safe areas can only be met when fresh air is blown into the sluice via an air feed pipe. However, when both gates are closed an overpressure is produced in the sluice area so that the blower gets into an unstable operation condition (“pumping”). Therefore there has to be a flap above the fire prevention gate on the tunnel side, which opens when a certain overpressure is reached in order to relieve the pressure. The inside pressure shall be set to about 75 PA because when opening a gate pressure is transformed into velocity so that there is already an air velocity of about 11 m/s at the mere opening. This inside pressure effects one sluice gate with a pressure of about 172 kN so that an electro-mechanical or equivalent opening facility is required in order to open the gate for an adolescent or a handicapped person.
Vehicle movements in the main tunnel with pressure and sucking forces of more than 2,000 kN/m² can destroy gates when the lock is non-secured so that an unlocked gate must cause a fault report. The blowers are mostly installed in the basins of the life-saving tunnels. In passable life-saving tunnels the axial blowers are installed in niches or portals and the whole tunnel is put under pressure. Hereby, a “pumping” of the blower is also prevented by relief valves. The exact overpressure for the opening of the relief valve depends on the respective access tunnel and can only be defined during test operation.

2.6.2. Sluice doors and sluice gates; Pressure relief

According to ÖBFV-RL A –12 both slice gates have to be fire resistant, T 90. It must be possible to open them into escape direction and they must be protected against unintended slam shut.

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Their construction must be in a way that it can be charged with a load of ± 4000 N.

As the number of sluice gates is an important cost factor, it is intended to produce them in series and make a door stop on one side of the openings so that constructional deviations of the light opening do not influence the production.

Just like the doors the pressure relief flaps also have to be made according to the fire protection regulations because a failure of the aeration system may always be possible. They have to be kept shut except in an emergency because otherwise the smooth operation of the railroad traffic might get interrupted.

2.6.3. Air feed duct

In life-saving wells air feed ducts on the pit wall of the downward tunnel lead into the sluices and then join the air pipelines planned on the sluice ceiling. Their cross-section is designed to be about 1,50 m² in order to keep the resistance and especially the noise level within limits. Sluices with a cross-section 2,50 / 2,50 m require an air volume of 18,80 m³ / h. In order to avoid fumigating of the escape routes in the stairways, a ventilation flap built in after the inner sluiceway gates shall provide for aeration in escape direction when fume is detected in the sluiceway itself.

In life-saving tunnels the tunnels to the sluiceways function as air feed ducts. From the tunnels the air enters the sluiceways via adjustable flaps. Even here, the pressure is actually relieved via the valve above the sluice gate on the side of the main tunnel.
2.6.4. Control and supervision of blowers

A most decisive aspect for keeping escape routes free from fumes is the punctual start of the blowers in order to produce an overpressure in the sluiceways of the life-saving wells and life-saving tunnels. If the blowers are only switched on when the first sluice gate is opened, a thickening with smoke of the escape routes cannot be excluded because the acceleration of air masses takes time.

Therefore, it is intended to immediately switch on the blowers in the area of an accident via the central monitoring system in case an emergency is reported. If this does not happen, the blower gets automatically switched on when the panic handle of the outer sluiceway gate is opened whereupon the emergency gets reported.

3. SUMMARY

Beside the by-pass of Innsbruck the design and the execution of the Inntal line marks an essential part of the Brenner basis project.

The basics for the design, especially concerning the safety facilities for self-rescue – safe areas, sluiceways and aeration of sluiceways just as lifting systems for people – could partly not be defined properly due to missing concrete directives.

The design process laid the basis for further building projects.

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