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 Inn valley 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 have to be made in a leak proof way. According to water right law this is an indispensable general demand. Otherwise there will be an important interference with groundwater 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. 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.

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. 

*Illustration 1.2.1: suction well volume:*

<table>
<thead>
<tr>
<th>Suction well volume for ( n = 8 ) times p.h.</th>
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<tr>
<td>( n = \frac{1}{(V/Z + V/(P-Z))} )</td>
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<tr>
<td>( V = \text{volume} )</td>
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<tr>
<td>( I = \text{inflow} )</td>
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<td>( P = \text{pump-capacity} )</td>
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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.

*Illustration 1.2.2: example of a pumping station in a life-saving stairwell*
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 many 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. Access from the life-saving tunnels is exclusively granted via a screwed manhole. 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). These guidelines define the state of the art in technology and may be seen as the basis for the authorization procedure of railroad constructions.

As for road tunnels these guidelines correspond with the guide line 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.

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 at all.

Every 500 m there must be cross connections from the traffic tunnel to the life-saving tunnels or the emergency stairwells respectively. Between the traffic tunnel and the life-saving tunnels/emergency stairwells there must be sluiceways of at least 12 m length.

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 has to be 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 in one of several railway carriages and the train cannot leave the tunnel for technical reasons any more. The people escaping from the traffic tunnel must 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.

At a fire size of about 60 MW, which is the basis for the calculation of the necessary fresh air, the critical longitudinal velocity $u/m/s$ is 3 m/s. With the necessary fresh-air volume $V$ ($m^3/s$) can be calculated from the equation $V = A \cdot u$ when the escape tunnel cross section $A$ ($m^2$) 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. This ratio produces a force which makes the tunnel air move into direction of traffic. 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 lit. /2/.

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 $A_1 \cdot cw = A_2 \cdot cw = A_{cw}$. In the given case this results in a value of $A_{cw} 120 m^2$. With the given equation the velocity as well as the pressure course can be calculated.

Illustration 2.4.2.1 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 ($A_{cw}$) 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.
Illustration 2.4.2.2 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.

Illustration 2.4.2.3 shows 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 illustration 2.4.2.3. 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.

Illustration 2.4.2.3 / pressure course in the main tunnel VOMP when a train stops at m 4900 and an oncoming train stops at m 8000 (A*cw = 120m*m, pressure difference p1-p2 = 0 N/m*m)

2.5 Dimensioning of blowers
The necessary pressure increase diff.p, which is to be supplied by the respective axial blower, mainly consists of 3 parts:
- diff.pFD (losses by friction, diversion etc.)
- diff.pTh (thermic influences)
- diff.pTM (influences by train movements in the main tunnel)

The efficiency of the blowers results from the equation:

\[ P = V \cdot \text{diff.pT} / \gamma \nu \] \hspace{1cm} 2.5.1

\( V \) is the required air volume and \text{diff.pT} the required total pressure increase.

\[ \text{diff.pT} = \text{diff.pFD} + \text{diff.pTh} + \text{diff.pTM} \] \hspace{1cm} 2.5.2

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

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 up to 250 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 sluice gates have to be fire resistant, T 90. It must be possible to open them electro-mechanically into escape direction and they must be protected against unintended slam shut. Their construction must be in a way that it can be charged with a load of ± 4000 N.

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 / s. In pre-pressed tunnel profiles or tunnels dug by miners the air volume is larger.

In life-saving tunnels the air feed ducts to the sluiceways are the tunnels themselves. From the tunnels the air enters the sluiceways to the main tunnel 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.

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