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Longitudinal - and Transverse Ventilation in Road Tunnels

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Abstract. Vehicles, which are driving through a road tunnel, emits exhaust fumes/1/. These exhaust fumes are dangerous for the people and therefore they must be diluted with fresh air. Three different ventilation systems are used in a road tunnel to dilute these fumes /2/
- longitudinal ventilation with jet fans
- semi transverse ventilation
- transverse ventilation

Each ventilation system has its advantages and disadvantages /3/.

1. Introduction

More than 300 km road tunnels are built in Austria. This was necessary, because the main ridge of the Alps is running from east to west through our country. A lot of snow is lying and avalanches are possible in wintertime in the mountain area. For that reasons winter safe road connections from north to south through our country need long road tunnels through the Alps.
One of the most important elements of a road tunnel is the ventilation, which is necessary to bring fresh air into the tunnel in normal case of operation, respectively to suck off the exhaust air under normal condition or smoke in case of fire.
Good air quality in the tunnel is the main lay-out parameter for the ventilation. Several computer programs had been developed to calculate the fresh air demand, which must be blown into the tunnel to guarantee the necessary air quality. The fresh air demand is different from tunnel to tunnel. It depends on the geometry of the tube (cross section area, inclination, sea level etc.), the amount of traffic (number of vehicles per hour) and the mixture of trucks and passenger cars (trucks produce mainly smoke and NO_x, passenger cars emit CO and also NO_x). Because of the legislation to reduce the vehicle emission of all new cars, the fresh air demand will be considerably lower in the future. Therefore the fresh air demand will be smaller for the same air quality in normal case of operation in the future.
In case of fire the ventilation system has to deal with different requirements /1/. In contrast to the normal operation in a tunnel, the smoke-extraction has to be enlarged in future in case of fire. This is necessary, because more goods are transported on the roads and the loads of the trucks become more and more dangerous. So the most important parameter for the tunnel ventilation will be the smoke extraction from the tunnel in case of fire. The possibility of extraction mainly depends on two factors, first the type of ventilation (longitudinal-, semitransverse- or transverse ventilation) and secondly the pressure – and velocity distribution in the tunnel

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itself.
In this paper the pressure–and velocity distribution in a 2.3 km long one-way tunnel (this means all vehicles travel in one direction) with two tubes and longitudinal ventilation will be shown in case of fire. Also a short example for the very complex pressure and velocity distribution in a long two-way tunnel (vehicles on one lane travel in one direction, vehicles on the other lane travels in the other direction) with only one tube with transverse ventilation under normal conditions is presented.

2. Pressure and velocity–distribution in a case of fire in a 2.3 km long one-way-tunnel with two tubes and a longitudinal ventilation with jet fans

2.1. **Basic tunnel and ventilation data.** The tubes are running from north to south and were planned before the bad fires in road tunnels (Mont Blanc/4/,Tauern-tunnel, St.Gotthardtunnel) happened. They will be opened in the year 2003. The continuous inclination is 1.5 %. The rectangle cross section is about $50m^3$. Both tubes are built in cut and cover procedure. A lot of connections between the both tubes are existing. This connections are closed with doors under normal conditions. But in case of fire in one tube, the people can open the doors and run quickly into the second tube. The doors are closed automatically after passing it. There are also two emergency exits in each tube, through which the people can go up into the open air or the fire-brigades can enter the tunnel. These emergency exits are overpressured by a radial fan and also closed in normal case of operation. At the west tube a roughly 300 m long gallery (which is open on the eastside) is linked with the tunnel. To avoid a recirculation of smoke into the east tube 50 m of the gallery are closed by a wall near the south portal. To avoid recirculation at the north portals a short wall between both tubes is installed. Because of the traffic prognosis and the assumption that the traffic-velocity below 30 km/h will be avoided, only six jet fans with a total thrust of 2280 N were installed. If the traffic velocity is high, the jet fans do not run, because the piston effect of the vehicle is strong and brings more fresh air into the tubes than it is necessary. The jet fans are only needed under normal conditions, when a strong wind pressure acts on the exit portals and the traffic velocity is low. But the jet fans are very important in case of fire. A sketch of the whole tunnel installation can be seen in fig. 2.1.1.

2.2. **Pressure distribution in both tubes in case of fire in the east tube.** When a fire occurs in one tube the ventilation has to be changed in both tubes. The most important item is, to prevent the smoke entering the second tube. People, who are fleeing from the fire and smoke can open the next connecting door to the second tube and enter the over pressured tube. Also the fire brigades can reach the fire place from the overpressured tube easily. A “save haven” is only possible, when the second tube has an overpressure against the fire tube. Therefore two pairs of jet fans have to be reversed and one pair is blowing in normal direction.

Fig.2.1.1.Sketch of the road tunnel

With this arrangement an overpressure can be achieved against the fire tubes. The overpressure can be enlarged, if an underpressure is produced in the fire tube. Therefore it is efficient to start only the pair of jet fans that are installed near the exit portals. The pressure-distribution in both tubes can be seen in fig. 2.2.1. The pressure-distribution in the west tube is presented by the thick black curve. The dotted line shows the pressure-distribution in the east tube (fire tube) when two jet fans are running only near the exit portals. If a second pair of jet fans are switched on to it in the tunnel middle, we get the semicolon curve. The interrupted line shows the pressure distribution when all six jet fans are running in the east tube. The diagram points out, that the pressure in the fire tube is higher (behind the pair of jet fans near the entrance portal) than in the safe-haven-tube. So smoke can enter into the west tube behind the jet fans, if people open the connecting doors. In case of fire in the west tube, very similar pressure conditions will occur in the east tube.

Fig.2.2.1: Pressure distribution in both tubes in case of fire in the east-tube

2.3. **Velocity-variation during the first time phase after fire alarm.** Because of the piston effect of the vehicles, the longitudinal velocity in the tunnels is very high. Calculations showed, that the longitudinal velocity is about 9 m/s till 10 m/s in case of normal traffic /4/. But in case of fire, very low longitudinal velocities are necessary. First because the smoke movement should be slow, otherwise a great part of the tunnel will be full with smoke within a very short time and the people cannot flee opportune timely. Secondly if the longitudinal velocity is higher than 2 m/s till 3 m/s, there will be no stratification (hot smoke on the top of the tunnel, smoke free zone near the bottom) and the people are trapped in smoke. So the velocity should be reduced if necessary with the jet fan very quickly. Calculations have been done, the velocity reduction can be seen, when no jet fans are not working (fig. 2.3.1.). If no vehicles are in the fire tube, the upper curve is the result. The longitudinal velocity decay is very quickly at the first moment and then slowly goes to zero. If the tunnel is full with vehicles (72 vehicles) and they drive out with a velocity of 100 km/s, so we will get the lower curve. The difference between these two curves is not very important.

Fig. 2.3.1: Velocity decay when all jet fans are switched out.

The figure 2.3.2. shows the velocity reduction when two (lower curve), four (middle curve) and six jet fans (upper curve) reversed (the thrust is much lower in the opposite direction) switched on and not stopped. We see that in this case the velocity will be stopped and reversed in the opposite direction. This can be very dangerous, because the smoke will be blown against the direction of the traffic movement.

The reversed jet fans must be switched off, before the flow direction is changed. These velocity distribution can be seen in fig.2.3.3. The lower curve shows the result, when the jet fans are stopped after 90 seconds. If the jet fans are stopped after 200 or after 250 seconds (curves in the middle) we have must better results. But to stop the jet fans after 490 seconds is too late. The longitudinal velocity will be reversed.

3. Pressure- and velocity distribution under normal conditions in a 6.4 km long one-way tunnel with two tubes and a transverse ventilation with four ventilation sections

To get more safety in case of fire long road tunnels (> 3 km) must have a transverse ventilation. A transverse ventilated tunnel has a fresh air duct, from which fresh air is blown into the traffic room every 12 m and an exhaust duct with the possibility to suck off exhaust air or smoke every 100 m through large exhaust dampers, from the traffic room into the exhaust duct. Both ducts are above the false ceiling. The pressure- and velocity distributions are very complex because of the three ducts. Fig. 3.1. gives an overlook of the complexity of these distributions for a 6.4 km long one-way tunnel with high traffic (3.600 vehicles per hour).

Fig.3.1 Velocity and pressure distribution in a transversely ventilated one-way tunnel .

The upper curve (marked with Δ) shows the pressure-distribution in the fresh air duct, the curve in the middle (signed with $\Box$) represents the pressure in the traffic room and the lower curve (marked with $\bigcirc$), renders the pressure in the exhaust duct. Because the high traffic and the high driving velocity of 100 km/s a big piston effect pushes the air with a air-velocity of roughly 10 m/s through the traffic room (lowest curve).
In case of fire the ventilation has to be changed in all ventilation sections. A safe haven in the second tube should be installed. An underpressure in the fire sections and an overpressure in the neighbor sections must be produced in the fire tube then it is possible to seek off the smoke quickly. But a particular investigation for each tunnel must be carried out.

4. Conclusion

The calculation showed, that the safety of people in case of fire in a one-way tube with longitudinal ventilation can be improved, by producing an underpressure in the fire tube and an overpressure in the second tube. With this arrangement a "safe haven" can be installed.
The pressure- and velocity-distribution in a transverse ventilation tunnel is very complex. A "safe haven" should be installed in the second tube. An underpressure in the fire section and an overpressure in the neighbor sections is necessary but particularly investigations for each tunnel have to be done.

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