Pressure and velocity distribution in the new tube of the Plabutschtunnel

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Abstract: The main ridge of the Alps lays just crosses Austria. Therefore it is not surprising that most highways in Austria do have to pass through a lot of road tunnels. Among these tunnels, some of the world longest tunnels for vehicle traffic are found. For safety reasons today all long road tunnels are planed with two tubes. Two tubes allow one way traffic in each tube. In the case of one way traffic it is easier to deal with the dense smoke which can be produced by heavy fires. However due do the very high cost in many cases only one tube was finished first and therefore the tunnel has to be operated with two-way traffic. After some years the second tube was opened and the traffic was changed to one-way traffic. The layout of the ventilation system must be a way, so that both cases -one way traffic and two way traffic- can be handled in normal operation and in fire situations. The authors developed system to model the ventilation system in normal operation and in fire situations. The model is used for two different situations. On the one hand the necessary regulations for the ventilation system under normal conditions are calculated, on the other and simulations can be done to foresee the influence of many changes of traffic conditions or changes in the ventilation system. For many cases the velocities in all ducts of the tunnel and the pressure distribution can be calculated.

Key-words: road tunnel, ventilation, piston effect, one-way – two-way traffic

Introduction

Each long road tunnel must be equipped with a ventilation system to avoid high concentrations dangers gases that are emitted by the vehicles. The piston effect of the vehicles that are driving in one direction is nearly same as in the other direction in case of two-way traffic. So the air in the traffic room will not be accelerated at all. No air velocity is in the traffic room. The total needed fresh air must be blown into the traffic room by the tunnel ventilation system. In case of one-way traffic all vehicles are driven in one direction and therefore a big piston effect accelerates the air in the traffic room in the direction of the moving vehicles. Thus a big air velocity exists in the traffic room and a lot of fresh air is pushed into the tunnel by the piston effect. Much less fresh air must be blown into the traffic room by the ventilation system in case of one-way traffic. The layout of the ventilation system must be therefore so that it may handle two-way traffic as well one-way traffic.

The Plabutschtunnel is a 10 km long transversely ventilated bypass tunnel for the city of Graz to avoid the through traffic [1]. The tunnel was planed 30 years ago for two tubes. But only one tube (east tube) was finished at that time because of the low traffic. So the east tube was operated with two-way traffic. The traffic was growing and growing in the last years, so the second tube (west tube) was built five years ago and opened for traffic in the year 2006. But now the first tube has to be closed because of new safety regulations for old tunnels. Therefore the second tube has to be operated with two-way traffic also about a period of one year. After renewing and reopening the first tube both tubes will be operated with one-way traffic.

Each long road tunnel must be equipped with a ventilation system to avoid high concentrations of dangers gases that are emitted by the vehicles. The piston effect of the vehicles that are driving in one direction is nearly same as in the other direction in case of two-way traffic. So the air in the traffic room will not be accelerated at all. No air velocity is in the traffic room. The total needed fresh air must be blown into the traffic room by the tunnel ventilation system. In case of one-way traffic all vehicles are driven in one direction and therefore a big piston effect accelerates the air in the traffic room in the direction of the moving vehicles. Thus a big air velocity is existing in the traffic room and a lot of fresh air is pushed into the tunnel by the piston effect. Much less fresh air must be blown into the traffic room by the ventilation system in case of one-way traffic. The layout of the ventilation system must be therefore so that it may handle two-way traffic as well one-way traffic.

1 Problem Formulation

The Plabutschtunnel has five ventilation sections with a length of 2000 m and tow shafts [2]. Only the northern section is ventilated from the north portal. All other sections are ventilated via the two shafts. A full transverse ventilation system was chosen because of safety problems in case of fire. Fig. 1 shows the cross section of the tunnel.

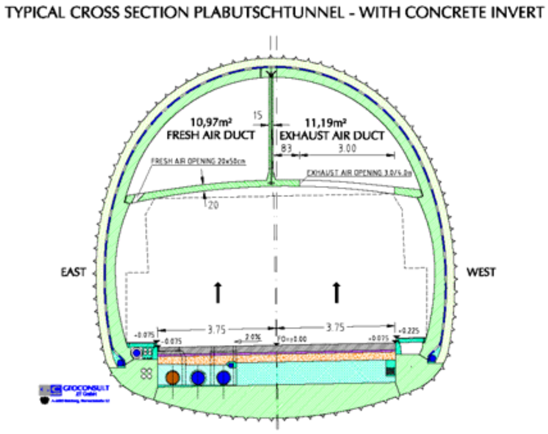

Fig.1 Cross section of the Plabutschtunnel

There are three ducts: the traffic room (vehicle duct), the fresh air duct and the exhaust duct. Fresh air is blown by the fresh air fan into the fresh air duct and through the fresh air openings into the traffic room where the dangerous gases are diluted to an accepted level. The exhaust air is sucked off through exhaust air openings into the exhaust duct and is blown by the exhaust fans into the atmosphere. The pressure difference between the fresh air duct and the traffic room as well between the traffic room and the exhaust duct is not constant. They are functions of the distance from the fans. For instance to blow the same amount of fresh air into the traffic room at each distance from the fresh air fan in case of two-way traffic we have to install different throttles along the fresh air duct into the fresh air openings. Also different throttles along the exhaust duct are necessary in the exhaust openings. The pressure in the traffic room is then constant and no air velocity in the traffic room exists. But if we change the traffic flow from two-way to one-way traffic a big air velocity (>10m/s) and a linear pressure distribution will occur in the traffic room. So the fresh air input into the traffic room and also the extracted exhaust is not any longer constant in the whole ventilation section with these throttlings. The throttlings are fixed and will not be changed when the traffic is changed from two-way to one-way traffic.

The calculation of the pressure and velocity distribution in all three ducts for different situations can be performed with the following non-linear differential equation system [3].

Fresh air duct

$$\frac{dp_f}{dx} = -\lambda_f \frac{1}{D_f}\frac{\rho}{2}u_f^2 sign(u_f) - \rho k_f u_f \frac{du_f}{dx}$$

$$\frac{du_f}{dx} = -\frac{f_f'}{F_f\sqrt{\zeta_{\tau f}+\sum\zeta_{ack}+\zeta_D}}\sqrt{(p_f - p_v)\frac{2}{\rho}+(1-\zeta_{\tau 1})u_f^2}$$

Vehicle duct

$$\frac{dp_v}{dx} = -\lambda_v \frac{1}{D_v}\frac{\rho}{2}u_v^2 sign(u_v) - \rho k_v u_v \frac{du_v}{dx} + \frac{\rho}{2}c_d\frac{F_V}{F_v}\frac{1}{\Delta L_1}\left[(V_1-u_v)^2 sign(V_1-u_v) - \frac{\Delta L_1}{\Delta L_2}(V_2+u_v)^2 sign(V_2+u_v)\right]$$

$$\frac{du_v}{dx} = -\frac{1}{F_v}\left(F_f\frac{du_f}{dx} + F_e\frac{du_e}{dx}\right)$$

Exhaust duct

$$\frac{dp_e}{dx} = -\lambda_e \frac{1}{D_e}\frac{\rho}{2}u_e^2 sign(u_e) - \rho k_e u_e \frac{du_e}{dx}$$

$$\frac{du_e}{dx} = -\frac{f_e'}{F_e\sqrt{1+\zeta_e}}\sqrt{(p_v - p_e)\frac{2}{\rho}+u_v^2}$$

Symbol declaration:

$p(N)$	static pressure
f	fresh air duct
$x(m)$	length coordinate
e	exhaust duct
$u(m/s)$	velocity
v	vehicle duct
$k(-)$	pressure conversion coefficient
$F(m^2)$	cross-section areas of the ducts
$V_1(m/s)$	vehicle velocity in x-direction
$V_2(m/s)$	vehicle velocity against x-direction
$c(-)$	drag coefficient
$F_V(m^2)$	frame area of vehicles
$\Delta L_1(m)$	distance of vehicles driving in x-direction
$\Delta L_2(m)$	distance of vehicles driving against x-direction
$f'(m^2/m)$	cross-section area per unit length
$\zeta(-)$	drag coefficient
$\lambda(-)$	friction coefficient
$\rho(kg/m^3)$	density

This equation system can be solved numerically.

2 Problem Solution

Fig. 2 shows the calculated velocity and pressure distribution in all five ventilation sections for two-way traffic.

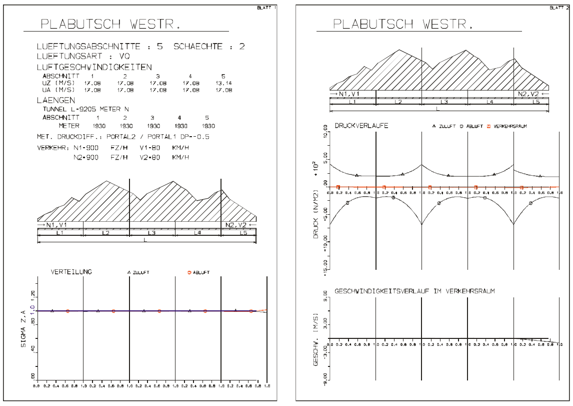

Fig.2: Velocity and pressure distribution in case of two traffic.

The injected fresh air volume (Sigmaz = 1) is equal to the extracted exhaust air (Sigmaa = 1) in ventilation section 1 to 4. In the section 5 more exhaust air is sucked off the fresh air is blown into the traffic room. So the air velocity from the south portal into the tunnel is achieved and no exhaust air can push out from the traffic room. This was a requirement from the city government. We can see that the pressure in the whole tunnel is constant. The fans are located for the north ventilation section (L1) at the north portal. All other fans are installed in the two caverns near the north respectively south shaft. Therefore the maximum pressure in the fresh air ducts and the minimum pressure in the exhaust ducts are near the shafts. If the traffic flow is changed from tow way to one-way only small variations in the velocity- and pressure distribution in the ventilation sections occurs only the air velocity in the traffic room is very much enlarged (fig.3).

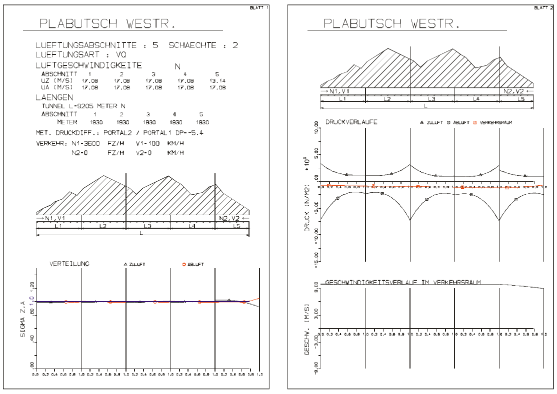

Fig.3: Velocity and pressure distribution in case of two way traffic

To reduce the high air velocity in the traffic room in case of one-way traffic less (73,5%) fresh air was blown into traffic room than extracted (100%). The result can be seen in fig.4. Now a under pressure occurs in the traffic room.

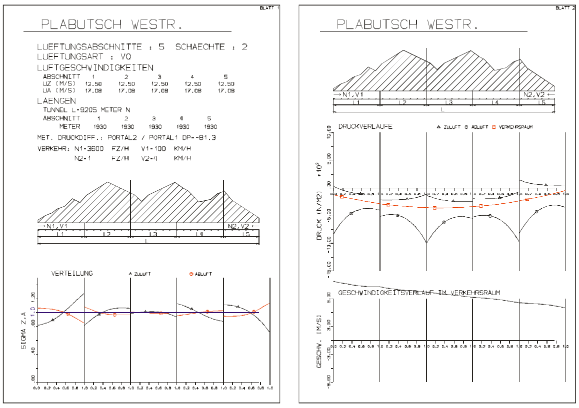

Fig.4 Velocity and pressure distribution in case of reduced fresh air injection.

The deviation from the constant fresh air injection (Sigmaz = 1) and the constant exhaust extraction (Sigmaa = 1) is high but is acceptable. The maximum respectively the minimum of velocity in the air ducts are always near the end of the ducts.

3 Conclusion

The pressure- and velocity distribution in all three ducts of a transversely ventilated tunnel can be calculated with the differential equation system. The air velocity in the traffic room is zero in case of two-way traffic. If we change the traffic from two-way to one-way traffic high air velocities occur in the traffic room. It is possible to reduce this air velocity a little bit (at the end of the tunnel) if we suck off more exhaust air the fresh air is blown into the traffic room.

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