Quantification of the Leakages into Exhaust Ducts in Road Tunnels with Concentrated Exhaust Systems

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INTRODUCTION

In recent years many countries have changed their requirements for ventilating road tunnels in an emergency. Traditional linear exhaust systems are no longer permitted; the smoke has to be exhausted from the tunnel close to the fire. The design of this new ventilation system requires different treatment in many ways.

One aspect is the leakage flow into the exhaust duct away from the exhaust point. The leakage generated by the under-pressure in the exhaust duct causes a leakage flow through the closed dampers and through the structure (drainage, cabling between road level and exhaust duct, doors and manholes, joint and cracks in the concrete structure). This additional flow can have a significant impact on the efficiency of the ventilation system and therefore must be considered in the design (e.g. [1]). The main difficulty today is to quantify the expected leakage flow into the exhaust duct because very few established bases are available.

In 2007 the Swiss Federal Road Authority ASTRA initiated a research project to extensively investigate leakages into exhaust ducts in road tunnels. The principal objective of the research work is to create a comprehensive basis for a better understanding of the leakages into smoke exhaust ducts. The research work has been articulated in five phases: 1) Literature search, 2) Leakage measurements, 3) Data Analysis, 4) Development of a method to extrapolate the measurement data to arbitrary tunnels and 5) Recommendations regarding prevention (e.g. reduction of leakages) and intervention (e.g. increasing ventilation capacity).

The project is well advanced and should by completed by mid-2010. This short paper focuses on phases 2 and 3.

MEASUREMENT

Measurement method

The leakage measurements have been carried out by an accredited laboratory (HSLU, Switzerland) using the well-proven tracer gas method using SF_6. The concept of this method is to inject a constant mass flow of SF_6 into the exhaust air at the open dampers. After about 60 duct hydraulic diameters downstream the tracer gas is well mixed with the exhaust air and the volume flow can be calculated from the measurement of the concentration of the tracer gas.

Although the tracer gas method is relatively complex and sensitive (cross sensitivity for vapor) it gives important advantages over a velocity based method (i.e. system measurement). The main advantages are: a) it is independent of the duct geometry and the duct cross section area b) an undisturbed incident flow is not required and c) it has no impact on the pressure losses in the duct.

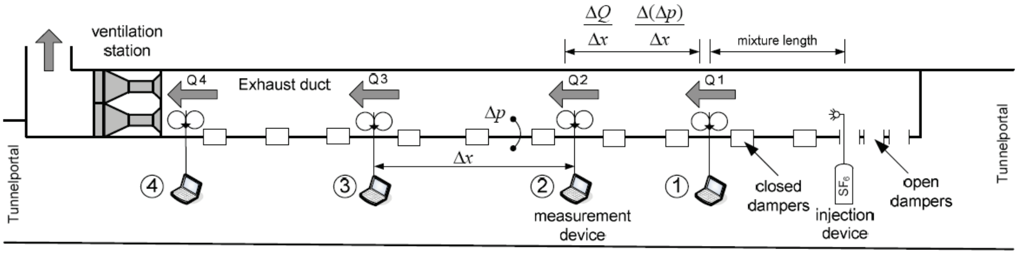

Figure 1: Measurement setup

Tunnels

Between August 2007 and September 2009 a total of 16 leakage measurement campaigns in 10 different Swiss tunnels were carried out (Table 1). In order to acquire a comprehensive set of data the tunnels cover a wide range of types considering geometry, age, construction and topology.

Table 1: Measured tunnel tubes

Nr.	**Tunnel**	**Tube**	**Opening**	**VS-Pos.** (a)	L_{Tunnel} **[m]**	A_{AK} **[m^2]**	**Date**
1	Flimserstein	-	2007 (b)	T	2’922	11.5	22.08.07
2	San Bernardino	Süd	1967 (c, d)	U	6’600	11.0	09.10.07
3	San Bernardino	Mitte	1967 (c, d)	U	6’600	11.0	10.10.07
4	Giswil	-	2000(b)	L	2’066	11.2	16.01.08
5	Raimeux	-	2007(b)	T	3’211	9.9	20.02.08
6	Leissigen	-	1994	T	2’200	9.5	24.04.08
7	Aescher	Basel	2009(b)	L	2’142	10.2	17.06.08
8	Aescher	Chur	2009(b)	L	2’175	10.2	17.06.08
9	Stägjitschuggen	-	2008(b)	L	2’302	12.4	23.09.08
10	Üetliberg	Basel	2009(b)	T	4’439	16.7	22.10.08
11	Üetliberg	Chur	2009(b)	T	4’499	16.7	23.10.08
12	Kirchenwald	Nord	2009(b)	L	1’530	13.0	03.12.08
13	Aescher	Basel	2009(b, e)	L	2’142	10.2	17.03.09
14	Aescher	Chur	2009(b, e)	L	2’175	10.2	17.03.09
15	Islisberg	Luzern	2010(b)	U	4’950	8.5	24.08.09
16	Islisberg	Zürich	2010(b)	U	4’950	8.5	26.08.09

(a) arrangement of the ventilation station(s): L = ventilation station at one portal, U = ventilation stations at both portals, T = ventilation station in the middle of the tunnel
(b) new tunnel originally built with concentrated exhaust system
(c) old tunnel with concentrated exhaust system added later
(d) refurbished 1991 – 2008
(e) second measurement

Installation

For the measurements 1 or 2 injection devices and 2 to 4 measurement devices have been required and the time required for one set of measurements was between 12 and 20 hours.

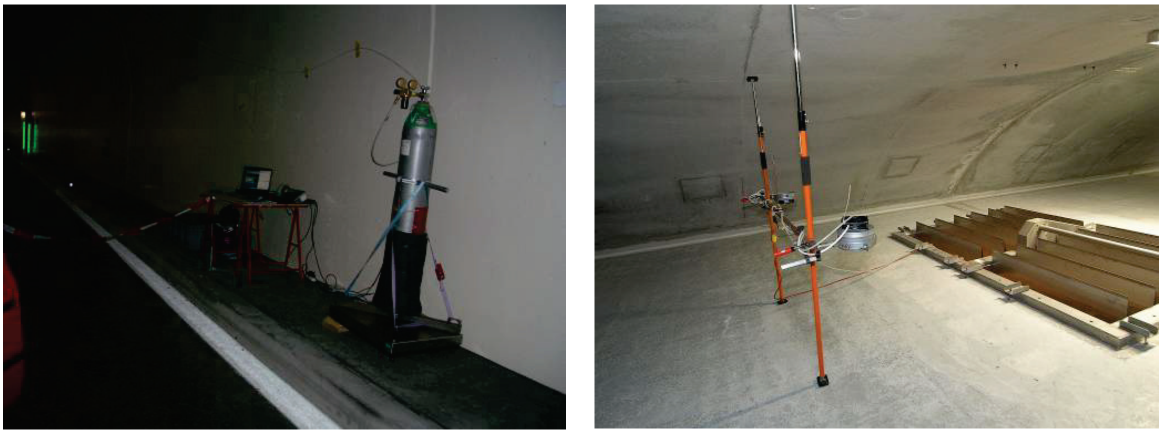

Figure 2: Injection station (left in the tunnel, right in the exhaust duct)

Figure 2 shows an injection device with the SF_6 gas bottle, the dosing system and the data logger in the traffic room and the injection into the exhaust duct which is connected by a small tube through the open damper.

Figure 3 shows a measurement device. In the exhaust duct three suction points, a compressor and sensors for absolute and difference pressures, temperature and humidity are installed. The gas analyser and data logger are located in the tunnel and connected to the suction points by several tubes and cables. Because the dampers are closed in this part of the tunnel, it can be a challenging task to run the tubes and cables from the exhaust duct to the traffic room. The best solution was to open the corresponding damper and run the tubes and cables through it and temporary close it with a wooden board from the tunnel side.

Figure 3: Measurement station (left in the tunnel, right in the exhaust duct)

MEASUREMENT RESULTS / DISCUSSION

In Figure 4 the measurement results (specific leakage versus pressure difference) for two tunnels with completely different behaviours are shown. The specific leakage is defined as the leakage per meter duct.

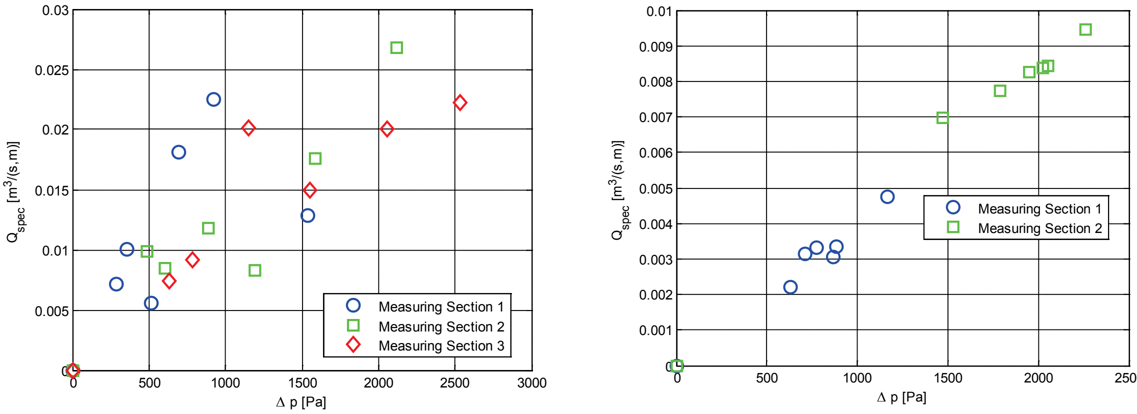

Figure 4: Results from Stägjitschuggen Tunnel (left) and Islisberg Tunnel (right)

The leakages for the Stägjitschuggen Tunnel vary over a wider range for the same pressure difference and the regression analysis shows that the leakage increases approximately proportional to $\Delta p^{0.5}$. The leakages for the Islisberg Tunnel are close together and the regression analysis shows that the leakage increases approximately proportional to Δp. One reason therefore is the inhomogeneous exhaust duct tightness that could be detected during the inspections. Another reason is the measurement uncertainty and the error propagation. For a typical situation with an exhaust flow of 150 m^3/s, a leakage flow of 10 m^3/s and a measurement uncertainty of 5%, the uncertainty in the leakage increases quickly to be of the order of the leakage itself. Therefore a single measurement is not very representative to generally quantify the leakage flow. Much more representative is an overall treatment which considers all measurement data. Figure 5 shows the specific leakage as a function of the pressure difference (scaled to a pressure difference of 200 Pa) for all new tunnels (127 data points) and old tunnels (32 data points).

The plot shows that leakage flow is significantly higher in older tunnels and tends to be relatively high even for moderate pressure differences (20 $m^3/s/km$ for 500 Pa). For new tunnels the leakage flow increases at a much lower rate with increasing pressure difference; for typical pressure differences of 500 Pa, 1000 Pa and 2000 Pa the leakage flows are about 5, 10 and 15 $m^3/s/km$ respectively. Considering Figure 5, the leakage flow increases approximately proportional to $\Delta p^{0.5}$ for new tunnels.

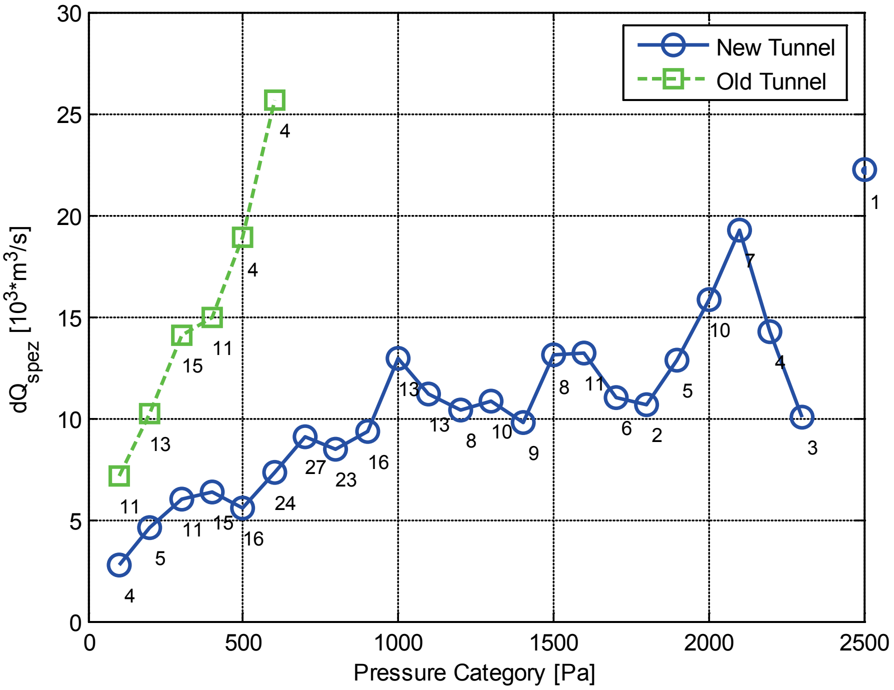

Figure 5: *Specific leakage vs. pressure difference for new and old tunnels. The numbers below the data points refers to the number of data points per pressure class.*

For practical application, we are developing a method to quantity the leakage with a dimensionless number based on a well known approach described in [2] and [3]. It is known that the leakage flow depends on many parameters. The impacts of some parameters are known and predictable (e.g. under-pressure, length). The impact of other parameters is rather random and unpredictable (e.g. age, sealing method). The idea of the method is to consider the known parameters in a mathematical way while combining all the others within a dimensionless number. This number can be defined based on the numerous leakage flow measurements. The concept thereby is to consider the leakage flow in a macroscopic way, accounting for no detail, as numerous attempts to calculate it in a detailed manner have failed.

REFERENCES

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