

## 2.09 PRESENTATION OF AUSTRIANS RECOMMENDED DISPERSION MODEL FOR TUNNEL PORTALS

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### INTRODUCTION

Street tunnels in cities are often suggested as solution to avoid daily congestions but also to prevent residential areas from high noise and air pollution emissions. In case of longitudinal ventilated tunnels high pollution levels may occur in the vicinity of the portals. The dispersion of pollutants from tunnel portals is considered to differ significantly from those of other sources, such as line or point sources. To the best of the authors knowledge, there exist currently two distinct dispersion models, which are especially designed to treat dispersion from tunnel portals. *Okamoto et al* (2001) proposed a diagnostic wind field model, where the dispersion is modelled using a Taylor-Galerkin-Forester filter method. *Oettl et al.* (2002) developed a Lagrangian-type model (GRAL TM 3.5=Graz Lagrangian model Tunnel Module Version 3.5), which is briefly described in the next section.

### METHODOLOGY

For the vertical dispersion a modified method according to *Van Dop* (1992) is utilized, which is able to account for buoyant plumes (i.e. when there exist positive temperature differences between the tunnel air and the ambient air).

$$dW = -\frac{W}{T_W} dt + B dt + \varepsilon_W^{0.5} d\omega_W, \quad (1)$$

where  $B$  is defined by

$$B \equiv \frac{g}{T} (\theta_{S_0} - \theta_A) \quad (2)$$

In eq. (1)-(2),  $W$  is the vertical speed of a particle,  $T_W$  is the Lagrangian time-scale for the vertical motion,  $\varepsilon_W$  is the dissipation rate for the vertical velocity,  $\omega_W$  are random numbers with zero mean and a variance equal  $dt$ ,  $g$  is the gravitational acceleration,  $\theta_{S_0}$  is the temperature of the jet stream at the portal,  $\theta_A$  is the ambient temperature, and  $T$  is the ambient temperature in Kelvin.

The dynamic behaviour of  $B$  in a diabatic environment can be formulated according to *Van Dop* (1992):

$$dB = -\frac{B}{T_B} dt - N^2 W dt + \varepsilon_B^{0.5} d\omega_B, \quad (3)$$

where  $T_B$  is the Lagrangian time-scale for buoyancy,  $N$  is the Brunt-Väisälä frequency,  $\varepsilon_B$  is the dissipation rate for buoyancy, and  $\omega_B$  is defined as  $\omega_W$ .

The horizontal course of the jet stream centre line is assumed to be governed by two forces, (i) turbulent friction due to differences in the velocity of the ambient wind parallel to the jet stream and the jet stream, and (ii) a pressure force caused by the ambient wind perpendicular to the jet stream. The first one of the above forces causes the jet stream to slow down, and the second one bends the jet stream towards the ambient wind direction. When K-theory is used as turbulent closing technique and homogenous turbulence is assumed over the cross-section of the jet stream, then the turbulent friction may be approximated by the term

$$\frac{dU_p}{dt} = -K \frac{\partial^2 U_p}{\partial y^2}, \quad (4)$$

where  $U_p$  is the flow speed along the jet stream (defined as x-axis), and  $K$  is the turbulent exchange coefficient.

The turbulent exchange coefficient is taken to be time-dependent and reads:

$$K = \alpha (1 + t), \quad (5)$$

where  $\alpha$  is an empirical constant.

From Bernoulli, the pressure force acting on the jet stream by the ambient wind can be assumed to be

$$\frac{dU_{nS}}{dt} = \frac{1}{2} \beta U_{nA}^2, \quad (6)$$

where  $U_{nS}$  is the jet stream velocity in y-direction,  $U_{nA}$  is the ambient wind speed perpendicular to the jet stream, and  $\beta$  is another empirical constant, which mainly reflects the area upon which the wind pressure acts. This constant is again assumed to grow with time (since the area covered by the jet stream increases) and is set:

$$\beta = \gamma (1 + t) \quad (7)$$

One main difference between GRAL TM 3.5 and the Japanese approach is, that GRAL accounts for wind direction fluctuations, which cause the tunnel jet also to vary in space. This assumption leads to an effective horizontal dispersion of the pollutants. While the eddies along the surface between the tunnel jet and the ambient air are expected to be a few metres in diameter, the change in position of the tunnel jet has typical length scales of tens of metres. Hence, the ambient wind direction fluctuations are expected to be very important for the dispersion process at all.

## RESULTS

GRAL TM 3.5 has been tested against experimental data from five different tunnel portals, namely the Enrei, Hitachi, Ninomiya tunnel in Japan (*Oettl et al.*, 2003), and the Ehrentalerbergtunnel in Austria (*Oettl et al.*, 2002). The Japanese tunnels are all located in complex terrain, while the Austrian tunnel is surrounded by rather flat topography. Meteorological conditions observed during the experiments showed a wide variation of wind speeds (0.6 – 6.2 m s<sup>-1</sup>), atmospheric stabilities (stable – unstable), and wind directions, such that it was possible to evaluate the model for a wide range of angles between tunnel jets and ambient winds including also head winds.

In the year 2000 another research project was launched by the Austrian ministry for traffic, innovation and technology. The project aimed at investigating the pollutant dispersion in the proximity of a city tunnel in Vienna (Kaisermuehlentunnel), where the portal is situated five metres below the surroundings. This is a particular difference in construction compared to all the other tunnel sites studied by now, which has an effect on the dispersion. Also, the traffic volume found in the Kaisermuehlentunnel is much higher than for the other tunnels mentioned above. In the frame of this project, four different models (ADMS, LASAT, MUMO, and GRAL) were compared (*Puxbaum et al.*, 2003). On the basis of this comparison, it was decided to recommend GRAL TM 3.5 for dispersion modelling from road tunnel emissions in Austria in a new national guideline in elaboration.

Figure 1 depicts results for average concentrations obtained with GRAL TM 3.5 for the Hitachi and Enrei tunnel in Japan. The spatial concentration distribution was simulated satisfactory, even though only a few experiments were made, which could be taken to calculate an average concentration at each receptor.

Figure 2 shows a scatter plot of observed and modelled concentrations for the Ehrentalerbergtunnel. Note, that in this case the scatter plot reflects concentrations paired in

space and time and are not average concentrations over several experiments. The scatter increases clearly with decreasing concentrations (i.e. with increasing distance to the portal). The correlation coefficient reads 0.72.

Figure 3 shows the modelled average NO<sub>x</sub> concentrations for westerly winds (>900 cases) for the Kaisermuehlentunnel. The largest deviation between the average modelled and observed concentration was found to be -13 %, except at M2, where there might be a problem with the determination of a proper background concentration.

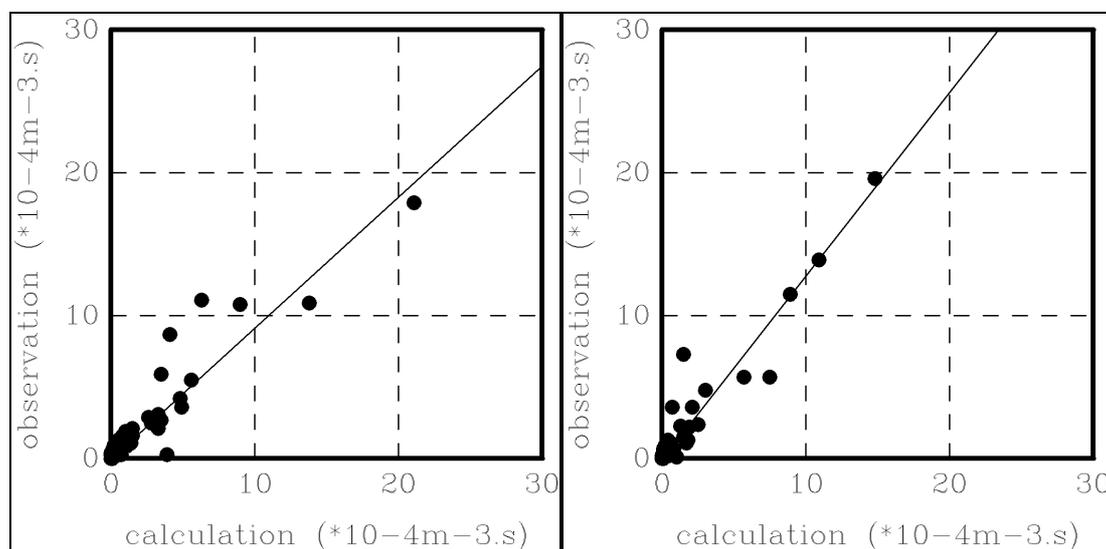


Figure 1. Scatter plot of mean concentrations obtained with GRAL TM 3.5 for the Hitachi and the Enrei tunnel in Japan (average values over 18 and 17 experiments).

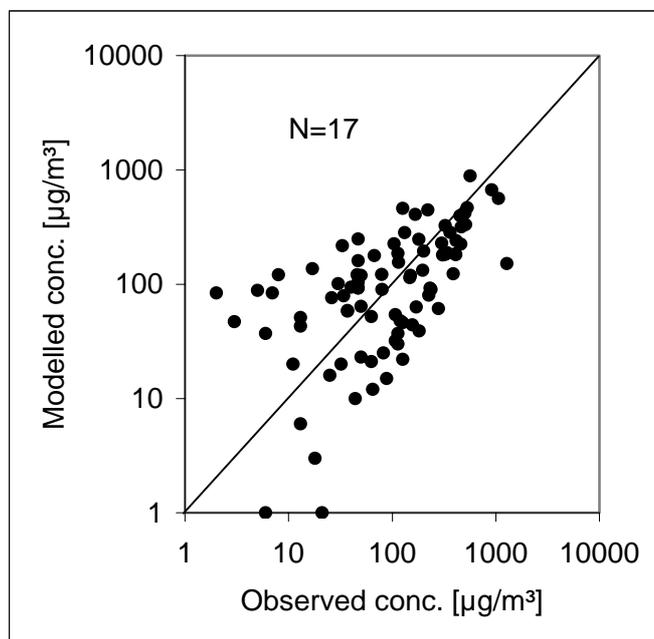


Figure 2. Scatter plot of observed and modelled concentrations for all tracer tests at the Ehrentalerbergtunnel.

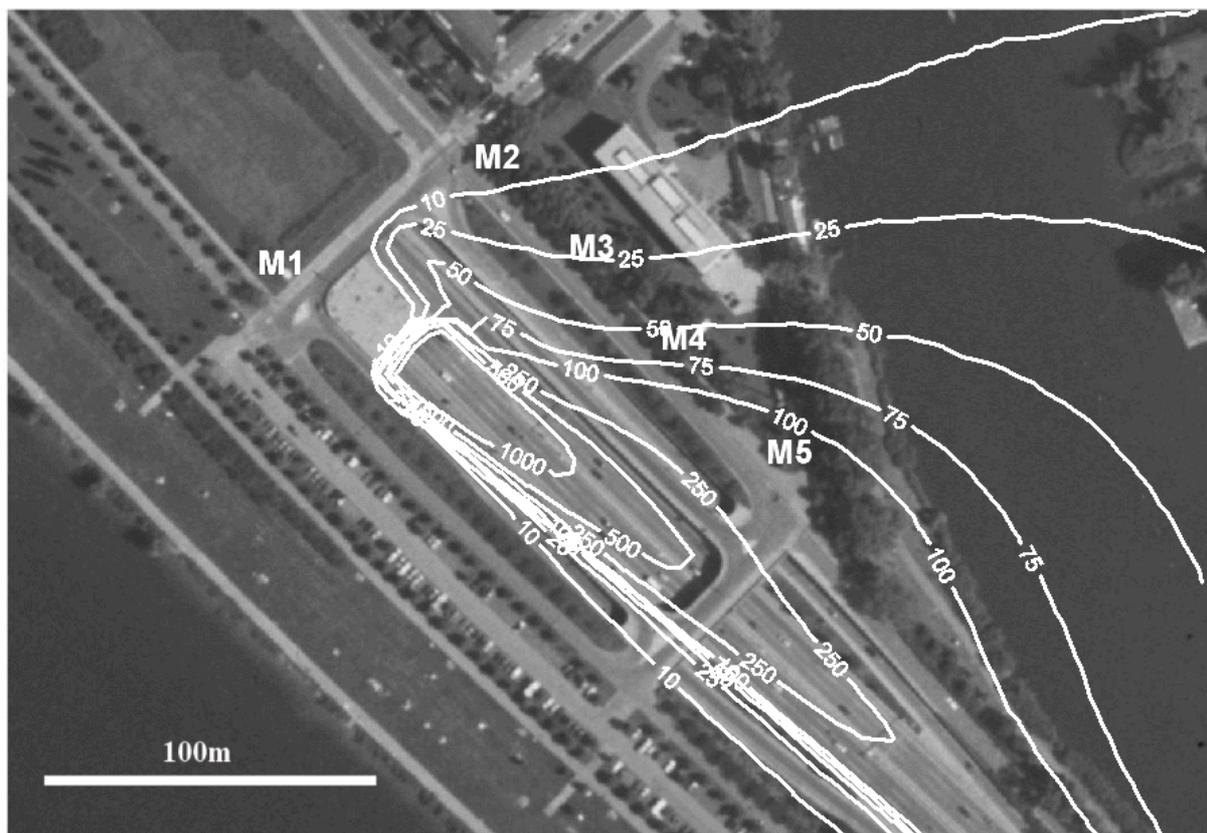


Figure 3. Mean simulated concentrations for NO<sub>x</sub> for westerly winds in [ $\mu\text{g m}^{-3}$ ] for the Kaisermuehlentunnel.

### CONCLUDING REMARKS

Due to the comprehensive testing of GRAL TM 3.5 against various data sets, and the obtained results, it can be said, that the model is able to be used for regulatory dispersion applications. The main disadvantage of the current version of the model is, that there exist empirical parameters in the model (eq. (5) and eq. (7)), which have to be determined by the model user. These parameters control largely the dispersion and have to be chosen carefully depending on the tunnel site. Besides the construction of the tunnel (at grade, below the surface), also the traffic volume has to be taken into account when selecting proper values for the empirical parameters. The range of values for those parameters given in the publications (Oetl *et al.*, 2004 and Oetl *et al.*, 2002) should guide users of the model to chose suited values and obtain therefore reasonable concentration distributions for other tunnel sites as well.

GRAL TM 3.5 has not been extensively tested when temperature differences between tunnel air and ambient air become negative. This might be often the case during summer days. Thus, care has to be taken regarding such situations, as one can expect high pollutant concentrations due to reduced vertical mixing.

The model and the experimental data sets for the Austrian tunnels can be obtained free of charge on request from the authors.

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