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POLLUTION DISPERSION STUDY IN BUILT-UP AREA FROM ROAD TUNNEL VENTILATION OUTLET

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ABSTRACT

In order to study pollution dispersion in built up area, aeraulic simulation at reduced scale in a boundary layer wind tunnel is intensively used at CSTB. The experimental set up and the associated procedures are described here. A comparison with complementary approaches developed at CSTB, numerical simulation and full scale measurements using tracer gas release is also provided.

1. INTRODUCTION

The urban automobile traffic has been continuously growing up for several decades. One of the answers to solve this problem is to build road tunnels. Unfortunately, for the air pollution point of view, the problem is not solved because pollutants produced by car engines are concentrated at tunnel outlets that are generally in built up areas. Before all urban planning decision for a new tunnel, a preliminary assessment is necessary to estimate the air pollution exposure in the vicinity of the tunnel exits and its ventilation chimneys.
In order to study such problems, different approaches were developed at CSTB : in situ measurements, numerical simulation and aeraulic simulation in a large boundary wind tunnel. In situ measurements are not possible at project stage and only simulation approaches are available. As any simulation is not perfect, it is important to evaluate the confidence level of the results obtained and, if possible, improve them. This is what we have tried to do by developing the aeraulic simulation process in the wind tunnel. In order to validate the experimental results a comparison with numerical simulation and full scale measurements has also been achieved.

2. WIND TUNNEL SIMULATION

2.1 The boundary layer wind tunnel

Differently from conventional aeronautical wind tunnels, a boundary layer wind tunnel is designed to reproduce the natural random properties of the wind at a reduced scale. The use of spires and large blocks at the entrance of the test section, roughness distributed on the floor upwind of the model allow to match the gradient mean wind and the turbulence levels and turbulence scales of the real wind at various reduced scales. The CSTB atmospheric wind tunnel, with a four meters wide and fifteen meters long test section, and an adjustable roof, is able to reproduce different kinds of winds from the low turbulent winds ("sea winds") up to the very turbulent winds ("large city winds") at different reduced scales, typically from 1/100e to 1/1000e.

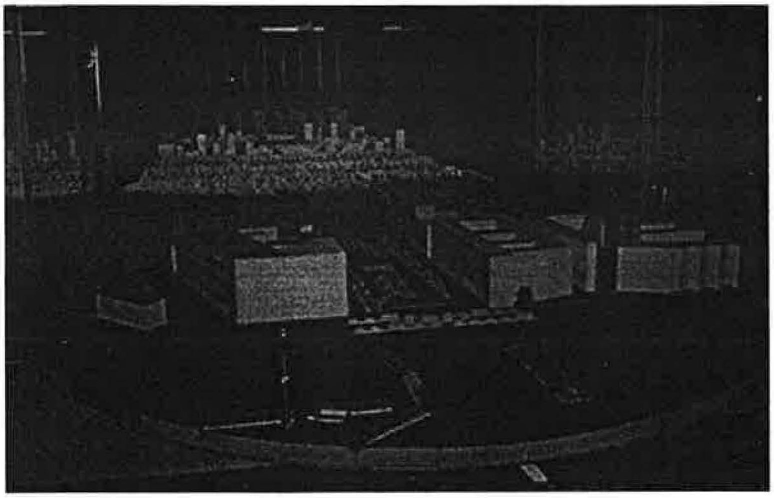

Figure 1. The atmospheric wind tunnel test section and the Porte Maillot diffusion model at a 1/100 reduced scale

The model itself built at the reduced scale of the simulated wind reproduces the pollutant source and its surroundings.

2.2 Atmospheric dispersion application

The study of pollutant dispersion is one of the boundary layer wind tunnel application's field. Differently from loads (pressures or forces) or environmental (pedestrian comfort) studies, strong winds are of minor importance here : high pollution levels occur only with moderate levels of winds and with stability conditions not always neutral.

This restrict the field of application of the wind tunnel which is generally able to study only neutral conditions. However, unfavourable stable meteorological conditions is a more general problem, not restricted to the tunnel outlet, and its unique solution is to reduce the pollutant emissions themselves.
Once restricted to neutral conditions, wind tunnel simulation is a perfect tool to study road tunnel outlet pollution :

- pollution is located on quite small urban area where turbulence produced by wakes and recirculations effects is predominant. This is easily simulated in the wind tunnel matching the geometry of the road tunnel outlet and reproducing its surroundings : topography, nearby buildings, vegetation.

- temperature of the polluted air of the road tunnel is similar to the ambient air so the similarity Froude condition can be relaxed, and the only additional condition to usual geometrical and wind similarity conditions is to reproduce the ratio of flow speeds between natural wind and internal tunnel flow.

- after a preliminary evaluation showing critical levels of pollution, the optimisation of the aerodynamic outlet of the tunnel is easy in the wind tunnel. The reduction of the recicurlating flows between the two adjacent tunnels, exit and entrance, and the effect of an additional ventilation chimney is also easily studied.

3. PRACTICAL USE OF THE WIND TUNNEL IN DISPERSION STUDIES

The first step of the experimental study and obviously the more important one is to define the more representative conditions of the full scale dispersion. These conditions are essentially function of :

- The wind direction and the wind speed V

- The airflow speed in the tunnel U (and direction of the flow and airflow speed in an adjacent tunnel if necessary)

In fact, the ratio U/V is the representative parameter

- The traffic conditions which fix the level of pollutant released in the atmosphere. The automobile traffic introduces also a turbulent mixing effect (driving effect in the wake of the vehicles) and increase the mixing of the pollutant with the ambient air.

Once defined all the representative conditions of the tests by using the meteorological data of the wind, the internal ventilation characteristics of the tunnel and hypothesis on the automobile traffic intensity; some technical problems have to be solved before being able to do the tests in a routinely way :

- In the wind tunnel, the pollutant is replaced by a tracer gas introduced in the airflow of the road tunnel. The ratio :

$$C = \frac{\text{concentration in the considered location}}{\text{concentration in the road tunnel}}$$

is the parameter used to transfer to full scale. Very accurate and fast response tracer gas system measurements like FID (Flame Ionisation hydrocarbons Detector) are available. With hydrocarbons like Ethane or Propane, they allow to study dispersion process with short duration tests. But using a tracer gas in the wind tunnel introduces a drift in continuous measurements if clean air is not used. A convenient way available at CSTB, is to use open air with a system of external doors for entrance and exit. We need then to be independent of external climatic conditions, so strong losses are introduced with a small entrance door. This limits the range of wind speeds available in the wind tunnel, but this is not a restriction for air pollution studies.

- Before to do any concentration measurement, flow visualisations are useful to do qualitative analyses of the pollution problem, and to optimise the location of the concentration measurements points. This is done introducing smoke inner the model of the road tunnel and visualising the plume at the outlet using flood lighting (fig. 2, 3).
Then, concentration measurements have to be made in numerous location, for different wind levels and directions, and different road tunnel ventilation flow speeds in agreement with the representative conditions considered for the study. Measurements can be considerably too long if a unique probe has to be moved for each location measurement, even if it is remote controlled.
Tubing systems like those used for pressure measurements with pneumatic switches is a way to improve the tests, but care has to be taken to have similar losses, not too high, in the tubes connected to the switches in order to keep constant and sufficient the flow rate traversing the probe.

- As previously underlined, the motor car traffic on the different lines of the road tunnel introduces a strong driving effect and increases the mixing of the pollutant with ambient air. In order to represent this "moving" similarity condition in the CSTB wind tunnel, very fast travelling bands (> 10 m/s) are used with models of cars and trucks connected to them (fig. 4). Consequently, in order to match the ratio cars velocity/wind speed, the flow speed in the wind tunnel is very low (< 5 m/s).

In the last step of this experimental study, the concentration measurements are combined with the wind statistics and the hypothesis on the traffic circulation and the tunnel ventilation characteristics to compute pollution levels associated to time exposures.
Depending of the kind of the pollutant (CO, NOx, ...) and the onset levels recommended in the rules, we can then conclude on the pollution risks and if necessary improve the design of the project up to obtain satisfactory results.

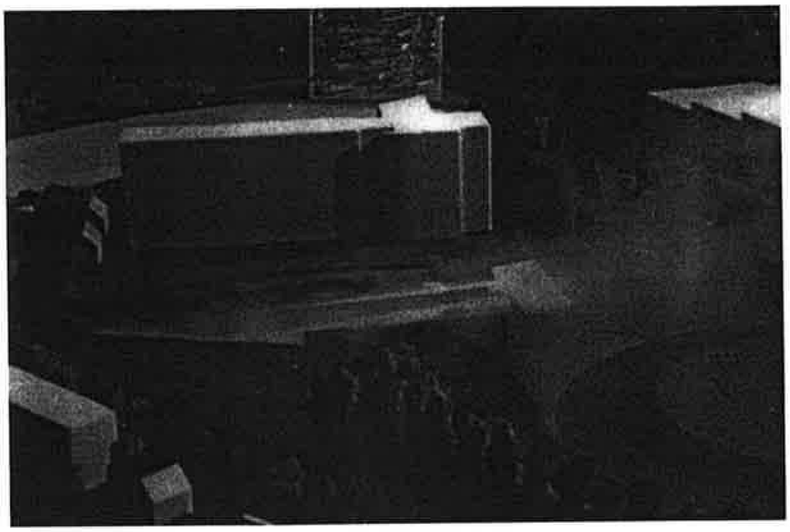

Figure 2. Flow visualisation, outlet of the road tunnel

Figure 3. Flow visualisation, additional ventilation chimney

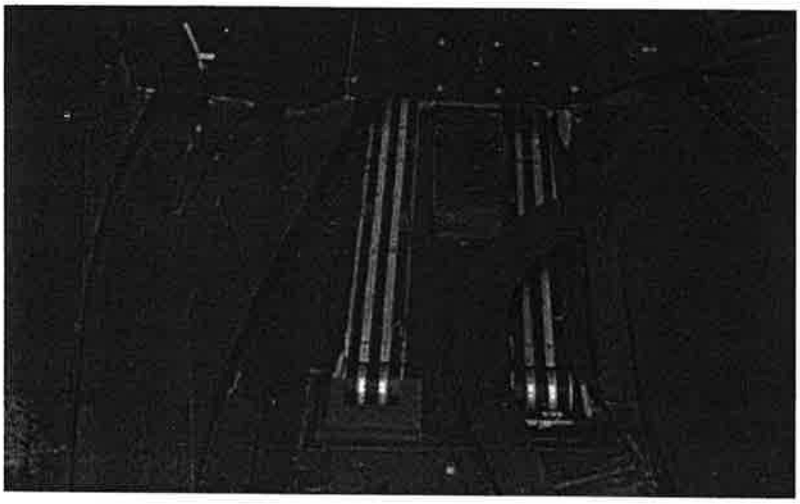

Figure 4. Fast travelling bands used to simulate the automobile circulation

4. COMPARISON WITH FULL SCALE MEASUREMENTS

In order to validate the results of the wind tunnel procedure, a comparison was done with full scale experiments carried out by J.P. Flori et al at Porte Maillot in Paris using SF6 tracer gas released inside a tunnel, 100 m upstream of the exit section. Bags and pump units allowed to sample simultaneously in fifteen locations 100 m around the tunnel exit. Detailed explanations of the tests are provided in Ref. [1]. Comparisons between various configurations of wind directions and wind speeds showed a general good agreement between the concentration field measured in the wind tunnel and the one observed on the experimental site (fig.6, 7). Some discrepancies are the results of non stationary conditions observed in full scale during the measurements periods.
Similar results were obtained by Delaunay et al. using a CFD numerical approach (PHOENICS finite volume code) [2].

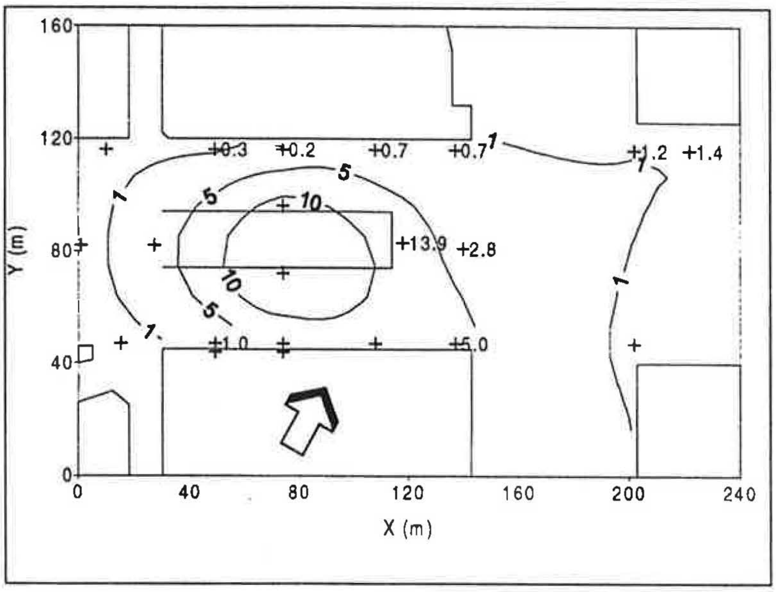

Figure 5. Comparison between full scale measurements (local values) and wind tunnel measurements (isolines) U/V=0.5 Wind direction : 240°

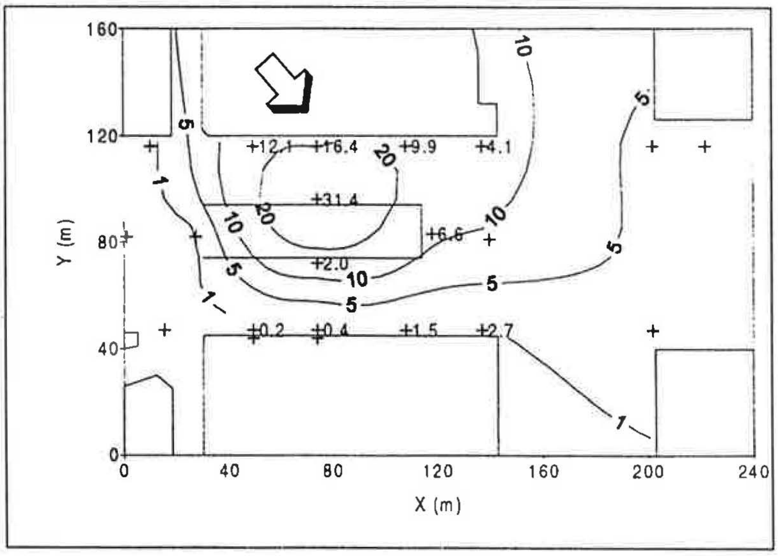

Figure 6. Comparison between full scale measurements (local values) and wind tunnel measurements (isolines) U/V=1 Wind direction : 345°

5. CONCLUSION

The interest of the simulation approaches is the reliable evaluations of pollutants diffusion problems at design stage of urban projects. The aeraulic experimental simulation developed at CSTB fulfil this as well as the numerical one. It offers the advantage to easily reproduce very complex conditions. An additional aerodynamic study of the road tunnel to design its ventilation system can be also an inexpensive complement to the diffusion study.

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