Study on an Air Quality Prediction System for Roadway Tunnel Portals

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1. Introduction

Air quality near roadway tunnel portals can be serious problem. Therefore, many models applicable to such a situation have been proposed to predict pollutant concentrations for automobile emissions. Tunnels are often constructed in an area of complex terrain or complex urban structure. In order to predict air quality for such an area, a numerical model may be necessary instead of conventional Gaussian plume models.

Japan Highway Public Corporation (JH) had carried out an intensive study on the development of a suitable air quality simulation model for the tunnel portal of a highway, including situations where the tunnel portal is surrounded by steep terrain. JH had carried out an extensive five-year study to develop the diffusion model for tunnel portals including in-situ experiments [1]. This model was validated by using the air tracer field experimental data for three different tunnels. JH has developed the prediction system based on this diffusion model. In addition, GRAL model, a practical tunnel portal model was developed by Oettl et al [2]. The prediction performance of the GRAL and JH models seems to be at similar levels. The outline of the model and its predictive performance has been discussed by Matsumoto et al [3] and Okamoto et al [4].

This paper describes an overview of the prediction system developed, which is currently in practical use. The meteorological preprocessor, traffic and road geographical data manipulation module are also discussed in this paper.

2. JH air quality prediction system

Japan Highway Public Corporation (JH) had developed an air quality prediction system for roadway tunnel portals (Atmospheric Dispersion Prediction Model for Complex Terrain near Tunnel Portals [ADIP-CTTP Ver.2.0]). The composite JH air quality prediction system consists of a wind field module and a diffusion module. The wind field module includes a tunnel sub-module. The diffusion module includes an emission sub-module and a meteorological sub-module. Figure 1 shows the overall layout of the composite system.

3. Predictive performance

In order to evaluate the refined JH air quality model, the calculated concentrations have been compared with observed data of the air tracer experiments (Table 1), consisting of 56 cases of SF_6 gas experimental data at three different tunnels.

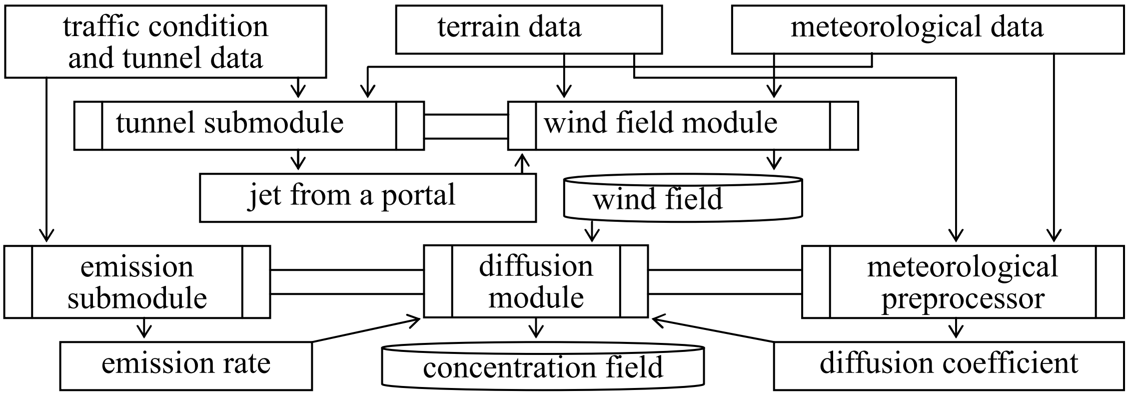

Figure 1 Outline of the proposed composite diffusion model

Table 1 Summary of the air-tracer field experiments

	Ninomiya tunnel	Hitachi tunnel	Enrei tunnel
Length and ventilation system	445m(-)	2439m(jet fan)	1800m(jet fan)
Highway	Odawara-Atsugi road	Joban expressway	Chuo expressway
Traffic volume	30,000 veh./day	24,000 veh./day	32,000 veh./day
Experiment date	20/01/94 to 01/02/94	03/02/95 to 09/02/95	23/11/95 to 29/11/95
No. of sampling sites:			
SF_6	64	85	86
NOx	17	-	36
No. of spot sampling	21	18	17
Tracer release period(h)	144	159	168

Figure 2 shows the results of the statistical evaluation for the hourly air tracer concentration data. The uncertainty of the observed data at the tunnel portal is too large due to the fluctuation of the jet diameter; therefore these data were excluded from further statistical evaluations. The statistical scores showed the correlation coefficients of 0.71-0.76, and the regression coefficients (slope) were 0.61-0.71. Evaluation scores for the segregated data by meteorological conditions are shown in Table 2. The correlation coefficients were fairly good for segregated dataset by wind direction, but the regression coefficient (slope) decreased for all three tunnels under stable or calm conditions. Further details of this evaluation study were explained by Okamoto, et al. [4].

4. Outline of the system

4.1 Hardware and software

The outline of the system hardware and software is shown in Table 2. The main software configuration of the prediction system consists of a start-up program, main program, user interface programs, and three sub programs, as shown in Table 3.

The numerical method used in this three-dimensional dispersion calculation is a modified version of the Taylor-Galerkin scheme, and the mathematical background has been discussed by Okamoto, et al. [1].

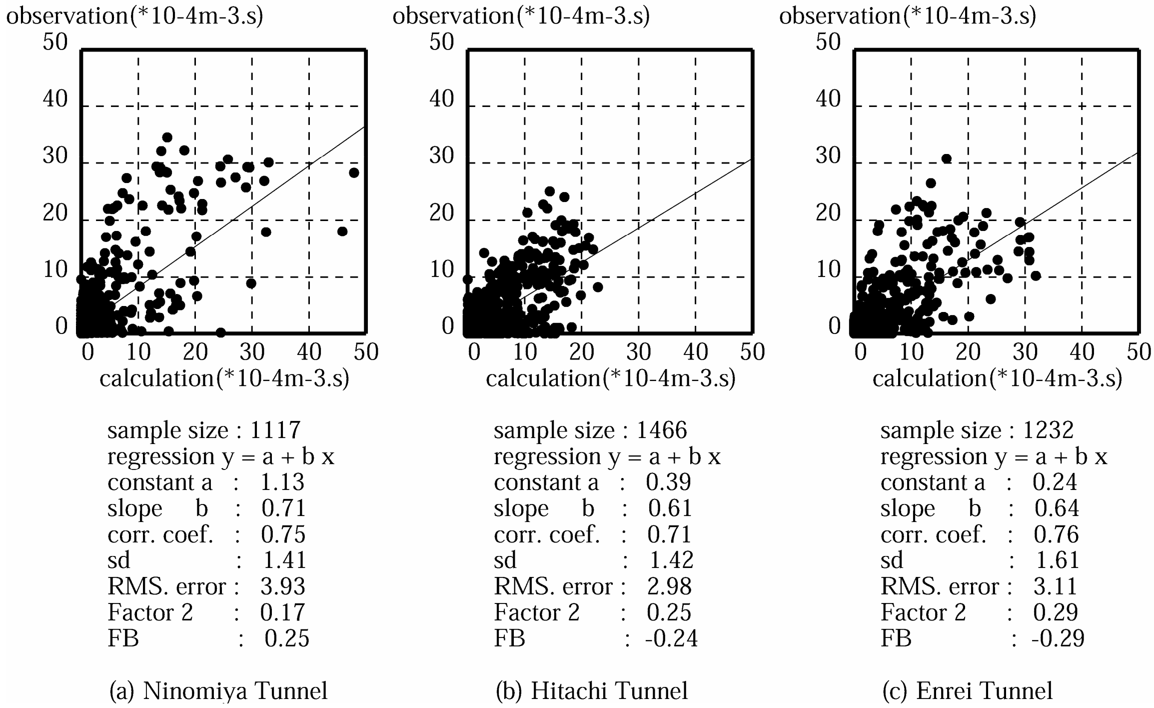

Figure2 Scatter diagram of hourly tracer concentrations and statistical evaluation scores (excluding the data in the direct vicinity of the portal)

Table 2 Configuration of Adip-cttp

Hardware	
Model	Sun Ultra Model 170E
CPU	Ultra SPARC-1
Memory	128MB
Software	
OS	Solaris 2.5.1
Window system	Open window
Compiler and Library	Fortran77, c, motif
Object module	20MB

Table 3 Composition of main and sub-module software

Module	Module name	Function
Start-up program	Adip_cttp	Initialization and start-up program
Main program	Xtdpmenu	Main user interface program
Sub program	Mscmain	Calculation of wind field over complex terrain using MASCON model
	Jetcal	Calculation of resultant wind field including jet stream from a portal using Jet model
	Difcal	Calculation of ambient concentration using Taylor-Galerkin numerical model

4.2 Geographical data manipulation module

One of the important input data is the terrain data for the geographical feature. It is necessary to prepare geographical data of about 1000m square area. The dataset consists of two-dimensional array of the terrain altitude, and the origin of this coordinate system should be consistent with the location of the portal of the target tunnel. Further, in consideration of plotting processed results, the x-axis of coordinates must be set along the road axis. Typical grid spacing for the terrain altitude is 5m intervals. Figure 3 is an example of the contour map based on the grid point altitude data. In this example, the contour line of the figure is displayed for every 5m in height. The portal of the tunnel is at the center of this map.

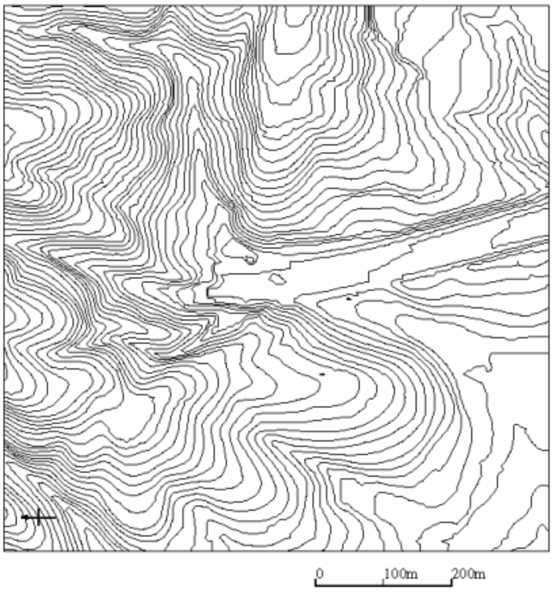

Figure 3 Example of a contour map based on the altitude data used for the Adip-cttp system

4.3 Meteorological preprocessor

The meteorological preprocessor provides three wind components u, v, w, and two diffusion coefficients Ky, Kz for all of the three dimensional grid points within the computational domain over the complex terrain. The wind field was estimated by using MASCON, a variational method, based on the observed wind speed and direction at the limited number of anemometer sites [5]. The upper-level wind speed is extrapolated by the power law rule. In order to reproduce the complicated wind field over the steep terrain, sufficient number of anemometer sites and appropriate site selection is very important. The jet velocity from the tunnel portal is estimated by the tunnel configuration and traffic conditions. Figure 4 is an example of a composite flow field vector. The composite flow field in Figure 4 is displayed by selecting the appropriate menu item in the output modele. The length and direction of the arrow in this figure shows the surface wind field estimated by this system.

The diffusion coefficient of the vertical direction Kz is estimated by the boundary layer meteorological model based on the atmospheric stability and ground roughness. The horizontal diffusion coefficient Ky is estimated by the time differentiation of the plume spread (sigma-y) based on the Pasquill-Gifford chart.

4.4 Traffic and road data manipulation module

The emission intensity along a road is calculated to set up the emission sources on the coordinate system. This emission source consists of a tunnel portal and a roadway. The roadway line source is divided into subsections corresponding to the computational grid cell. The tunnel portal is assumed as a point source, and its emission intensity is calculated by the tunnel configurations. Coordinates of the road are important in determining the position on the designated terrain feature. The emission intensity of automobile exhaust gases is computed based on the traffic volume, average driving speed, and emission factor for each car type.

4.5 Diffusion calculation module

Pollutant concentration at a grid point is calculated by a three-dimensional numerical model. The spatial derivatives are discretized by the Taylor-Galerkin method with Forester filtering [6]. The three-dimensional equation is solved by the operator splitting method. The concentration at time n+1 can be expressed by

$$C_{n+1} = A_x A_y A_z A_z A_y A_x C_{n-1}$$

Where A_x and A_y are the horizontal advection and diffusion operator, and A_z is the vertical operator including source and sink terms.

An example of a calculation result is shown in Figure 5. This contour map is the surface air tracer concentration around Enrei tunnel. In this figure, the computational domain for the diffusion calculation is the area within the smaller rectangle.

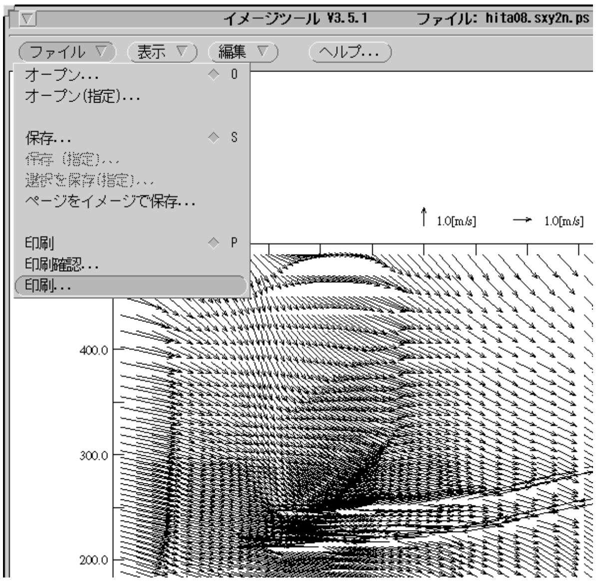

Figure 4 Example from wind field output module of Adip-cttp

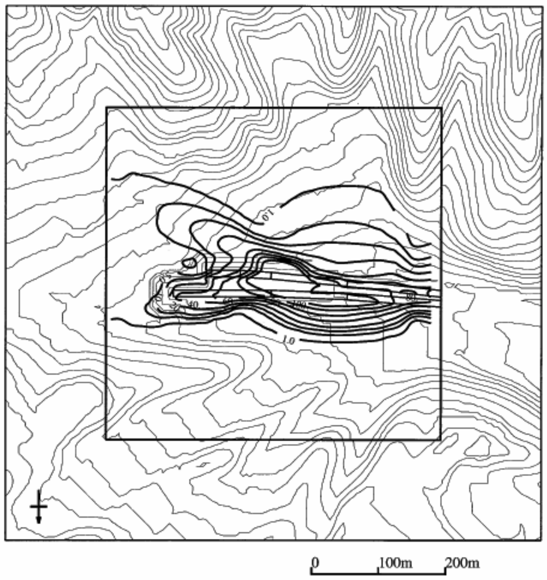

Figure 5 Example from diffusion field output module of Adip-cttp

5. Conclusion

In this paper, the outline of the atmospheric diffusion prediction system for a roadway tunnel was introduced. With the recent progress in computer technology, most computational problems may be solved within reasonable time frames. However, this does not mean that the atmospheric diffusion phenomenon can be easily reproduced with a numerical simulation. Fundamentally, for these cases where a physical phenomenon can be expressed by a set of mathematical equations, a trade-off problem may exist between the accuracy of approximation and practical usefulness including data requirements. This system was designed and developed for practical use, for example, environmental assessment and so on. At this stage, this system is already working for practical purposes, but much still remains to be improved for the system users.

Acknowledgments

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Reference

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