Evaluation of the JH air quality simulation model for 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. A tunnel is 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.

The Japan Highway Public Corporation (JH) has carried out an intensive study on the development of a suitable air quality simulation model for the tunnel portal of a highway, even if the tunnel portal is surrounded by steep terrain. A preliminary stage of this model was presented by Okamoto, et al. (1998a). This initial version of the model had a few weak points that predictive performance was degraded under stable and low-wind conditions based on the preliminary evaluation study by Matsumoto, et al. (1998). Recently some refinement for this model was completed, and critical validation has been carried out. The major objective of this paper is to present the results of this evaluation study.

2 JH dispersion model

The composite JH air quality model consists of a wind field module and a diffusion module. The wind field module includes a tunnel submodule and the diffusion module includes an emission submodule and a meteorological submodule. Figure 1 shows the overall layout of the composite model. Further details of the model are explained by Okamoto, et al.(1998a).

The wind field over a complex terrain is calculated with the MASCON variational wind field model, developed by Kimura, et al. (1996). This model was chosen from a number of existing models, after a comparative study on the prediction accuracy and required computational resources. The diffusion of automobile exhaust in the ambient air is determined by three-dimensional wind field, diffusion coefficient and emission conditions at a portal. The numerical scheme adopted in the previous version was the Taylor-Galerkin method, which had been selected after initial comparative study on the numerical methods (Okamoto, et al.,1998a). Since the Taylor-Galerkin finite element method generates computational ripples, it was replaced by the Taylor-Galerkin-Forester-filter method according to the results of our evaluation study on the numerical schemes by using the rotating corn and deformation flow problems (Okamoto, et al., 1998b). The emission submodule calculates the emission rate by using tunnel and traffic data. The meteorological module calculates the diffusion coefficient from the meteorological data and surface roughness.

The underlying investigation intends to further develop and improve the prediction performance of the initial version of JH air quality model. This initial evaluation study (Matsumoto, et al., 1998) indicated that predictive performance was poor for stable atmospheric conditions. Since air temperature of the jet stream from the portal is higher than that of ambient air in winter season, the buoyancy effect may not be able to be neglected. First, the tunnel submodule has been modified to express the rise of plume centerline height, especially under stable atmospheric conditions.

Therefore, the vertical component of the wind speed around the tunnel portal is additionally calculated by determining the heat buoyancy, and by presuming a constant rise of the jet centerline in the vicinity of the tunnel portal. This vertical component is used as an initial condition within the iteration of the MASCON model calculation. Secondly, in order to produce a more plausible flow field, the MASCON model is slightly modified to consider the total combined set of three dimensional jet stream data and ambient wind data.

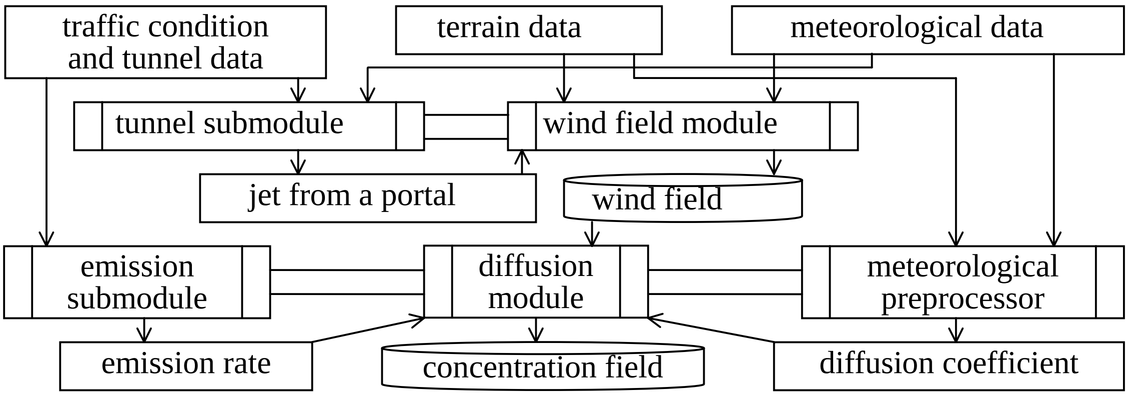


Figure 1 Outline of the proposed composite diffusion model.

3 Evaluation scheme

Recently, many evaluation studies have been carried out to confirm the predictive performance of the regulatory models (Hall, et al., 1999; McHugh, et al., 1999). The most commonly used statistics may be root mean square error (rmse) and correlation coefficient (r). Fractional bias (FB) and proportion of values within a factor 2 (Factor 2) are also important and commonly used.

$$\mathrm{Rmse} = \sqrt{\frac{1}{n}\sum\left(y_i - x_i\right)^2} \tag{1}$$

$$r = \frac{\sum\left(x_i - \overline{X}\right)\cdot\left(y_i - \overline{Y}\right)}{\sqrt{\sum\left(x_i - \overline{X}\right)^2 \cdot \sum\left(y_i - \overline{Y}\right)^2}} \tag{2}$$

$$\mathrm{Factor2} = \frac{n\left\{(x, y) \mid y_i/2 \le x_i < 2y_i\right\}}{n} \tag{3}$$

$$\mathrm{FB} = \frac{\frac{1}{n}\sum y_i - \frac{1}{n}\sum x_i}{\frac{1}{2}\left(\frac{1}{n}\sum y_i - \frac{1}{n}\sum x_i\right)} \tag{4}$$

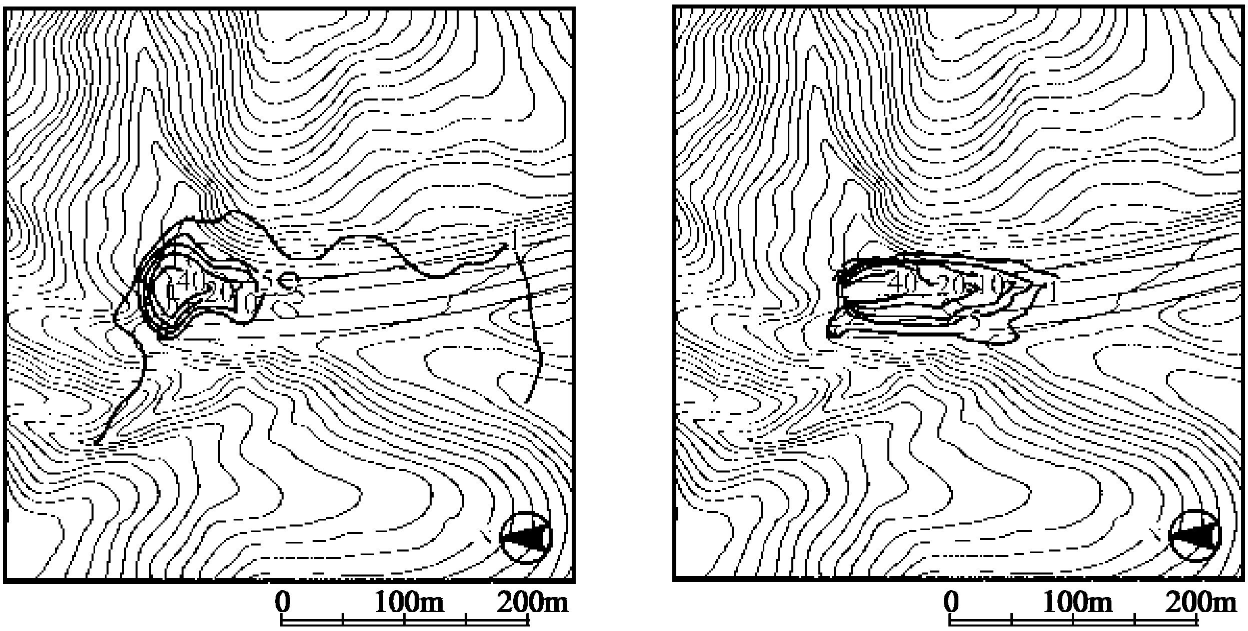
These scores were used in the statistical evaluation, combined with the subjective pattern recognition for calculated and observed contour maps.

4 Results and discussion

In order to evaluate the refined JH air quality model, the calculated concentrations have been compared with observed data of the air tracer gas diffusion experiments (Table 1), consisting of total 56 cases of SF_6 gas measurement data at three different tunnels. Figure 2 shows an example of comparison between calculated and measured surface air tracer concentrations, under stable atmospheric condition.

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



(a) Observation (b) Calculation

Figure 2 Observed and calculated surface concentrations under stable and low-wind condition (Run2-12)at Hitachi tunnel (unit of tracer concentration is ppb, contour lines are 5m interval height).

The observed concentration in the vicinity of the tunnel portal in Figure 2 indicated a very high and this tendency showed that the gas from the tunnel portal did not spread in the direction of the road axis, but remained near the portal in stable and low-wind conditions. The calculated decreasing tendency in the direction of the road axis by the previous version of the model was much smaller, which was not consistent with the measured data. However, the calculated results by this refined model shows a similar to the observed distribution in the direction of the road axis, even though the distribution in cross sectional direction is somewhat more limited than the measured results. This improvement may be the outcome of the inclusion of the buoyant effect of the jet stream.
Figure 3 also shows the results of the statistical evaluation for the hourly air tracer concentration data. The observed data at the tunnel portal have too large uncertainty due to the fluctuation of the jet diameter, therefore these data were excluded for further statistical evaluation. 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 not so bad for segregated dataset by wind direction, and the regression coefficient (slope) decreased for all three tunnels under stable or calm conditions. As for RMS error, a great deal of improvements could be seen, compared with the previous results (Matsumoto, et al., 1998).

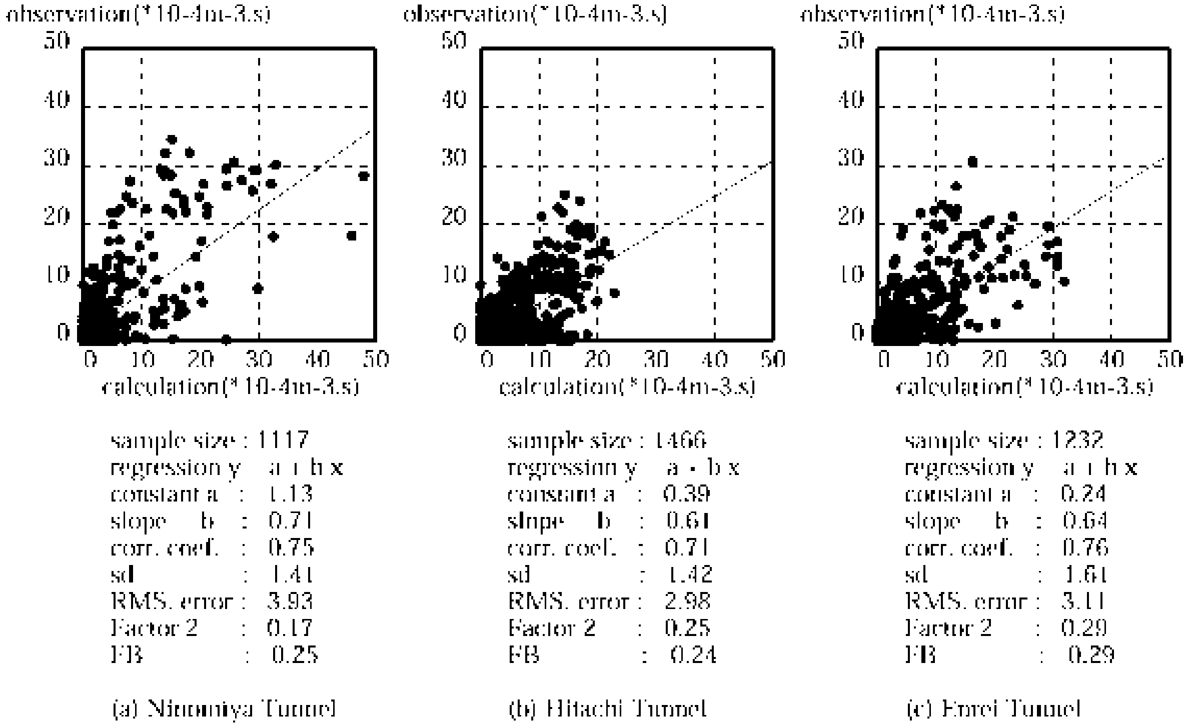


Figure 3 Scatter diagram of hourly tracer concentrations (excluding the data in the direct vicinity of the portal).

Table 2 Statistical evaluation scores for separated data sets based on the meteorological conditions.

Site	Condition		No. of case	No. of data	Correlation coefficient	RMS error (10-4m-3•s)	Regression y=a+bx		Factor 2	FB
							Constant a	slope b		
Ninomiya	Stability	Unstable	12	669	0.73	3.7	0.72	1.07	0.15	0.45
		Neutral	4	231	0.89	2.4	0.93	0.89	0.17	0.35
		Stable	4	217	0.85	5.6	1.50	0.50	0.24	-0.10
	Wind direction	Calm	3	166	0.86	6.3	2.08	0.47	0.22	0.00
		Cross wind	7	377	0.81	3.3	0.60	1.25	0.16	0.52
		Up wind	6	349	0.89	2.4	0.73	0.94	0.12	0.36
		Follow wind	4	225	0.61	4.5	0.70	0.80	0.22	0.10
Hitachi	Stability	Unstable	2	154	0.75	2.2	0.09	0.92	0.28	-0.01
		Neutral	13	1066	0.71	3.1	0.49	0.61	0.26	-0.20
		Stable	3	246	0.74	2.8	0.07	0.52	0.19	-0.58
	Wind direction	Up wind	8	646	0.70	2.7	0.46	0.66	0.29	-0.10
		Follow wind	10	820	0.72	3.2	0.32	0.58	0.22	-0.33
Enrei	Stability	Unstable	9	678	0.74	3.0	0.31	0.68	0.30	-0.19
		Neutral	5	356	0.85	2.3	0.27	0.81	0.35	-0.02
		Stable	3	198	0.79	4.4	-0.20	0.44	0.14	-0.92
	Wind direction	Calm	1	60	0.52	4.2	0.31	0.22	0.13	-0.99
		Cross wind	2	151	0.57	3.4	0.66	0.78	0.21	0.21
		Up wind	14	1021	0.80	3.0	0.17	0.65	0.31	-0.31

5 Concluding remarks

Correlation coefficients of the hourly data for three tunnels were almost between 0.7 and 0.9, and regression coefficients were mainly between 0.6 and 0.9. The fraction bias for three tunnels were between –0.3 and 0.3. These evaluation scores seem to show the possibility to use this JH air quality simulation model as a practical prediction tool. As overall evaluation, the refinements have resulted in improvement of the prediction performance.
Finally, in the underlying study the air quality simulation have been carried out including the influence of stable atmospheric conditions, but some examples have indicated that this influence is not necessarily always obvious. Further research may be necessary to clarify this point.

Acknowledgments

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