ACOUSTICAL LETTER

Efficient calculation on outdoor sound propagation by FDTD and PE methods

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1. Introduction

In recent years, various kinds of numerical simulation methods based on wave theory have been applied to predict outdoor sound propagation. Among them, the parabolic equation (PE) method [1] has been widely applied to investigate long-distance sound propagation under the influence of ground impedance and meteorological profiles. However, it is not necessarily applicable to arbitrary geometrical profiles such as banks and channels. On the other hand, the finite difference time-domain (FDTD) method [2] has been applied to the analysis of sound propagation over complex-shaped boundaries. However, the prediction is limited to a relatively small range due to the shortage of computer memory size. In this paper, an efficient method of predicting long-distance sound propagation is proposed by coupling the PE method and FDTD method.

2. Outline of numerical analysis

As a sound field under investigation, a 2-dimensional field (55 m(W)×25 m(H)) was assumed by setting a cross section of a hemi-free field with an infinite noise barrier. Figure 1 shows the positions of a sound source, receiving points and a noise barrier. As variations of noise barriers, three typical types shown in Fig. 2 were investigated; straight wall (Type 1), inverse-L wall (Type 2) and arc wall (Type 3). In the calculation, the highest frequency component was specified to be 1 kHz and the sound field was divided into square grids of 0.03 m. As the boundary conditions, all surfaces of the ground and barriers were assumed to be perfectly rigid. An outline of the calculation procedures proposed in this study is described as follows:

1. The sound field shown in Fig. 3 was analyzed by the FDTD method and impulse responses were obtained at all gird points on the vertical section indicated by the dotted lines.

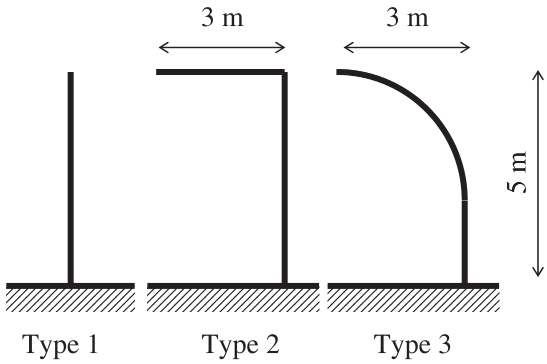

Fig. 2 Shapes of barriers under investigation.

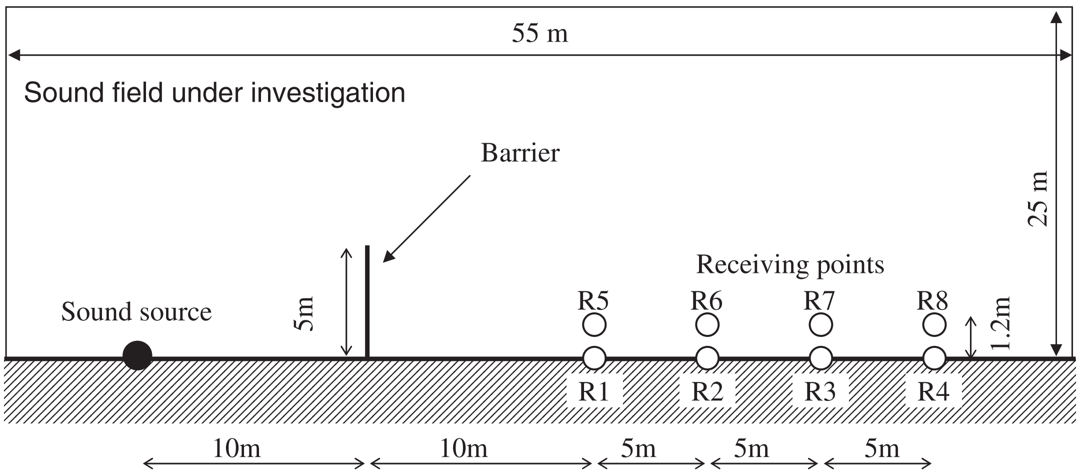

Fig. 1 Sound field under investigation.

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2. The impulse responses were analyzed by FFT and the spatial distribution of complex sound pressure on the line was determined for each single frequency.
3. By setting the sound pressure distribution as the initial condition, the sound field shown in Fig. 4 was analyzed by the PE method and complex sound pressure at each receiving point was calculated for each single frequency, respectively.

3. Calculation results

To examine the calculation accuracy of the proposed method, the whole sound field (55 m(W)×25 m(H)) was

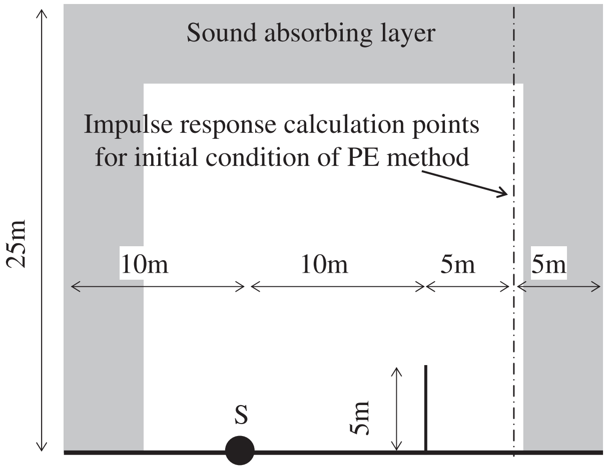

Fig. 3 Sound field for FDTD calculation.

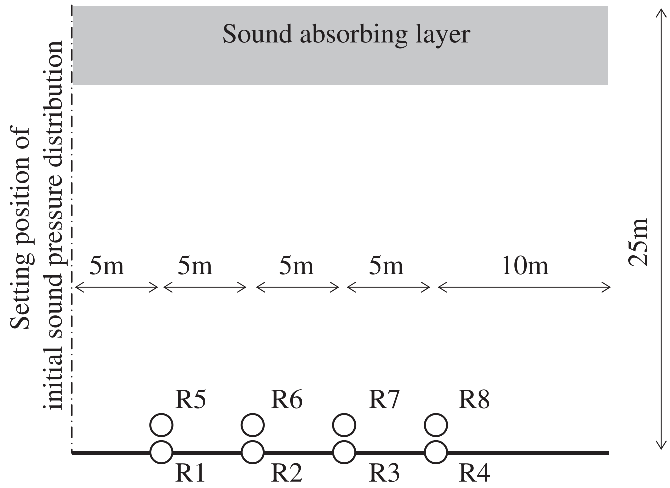

Fig. 4 Sound field for PE method.

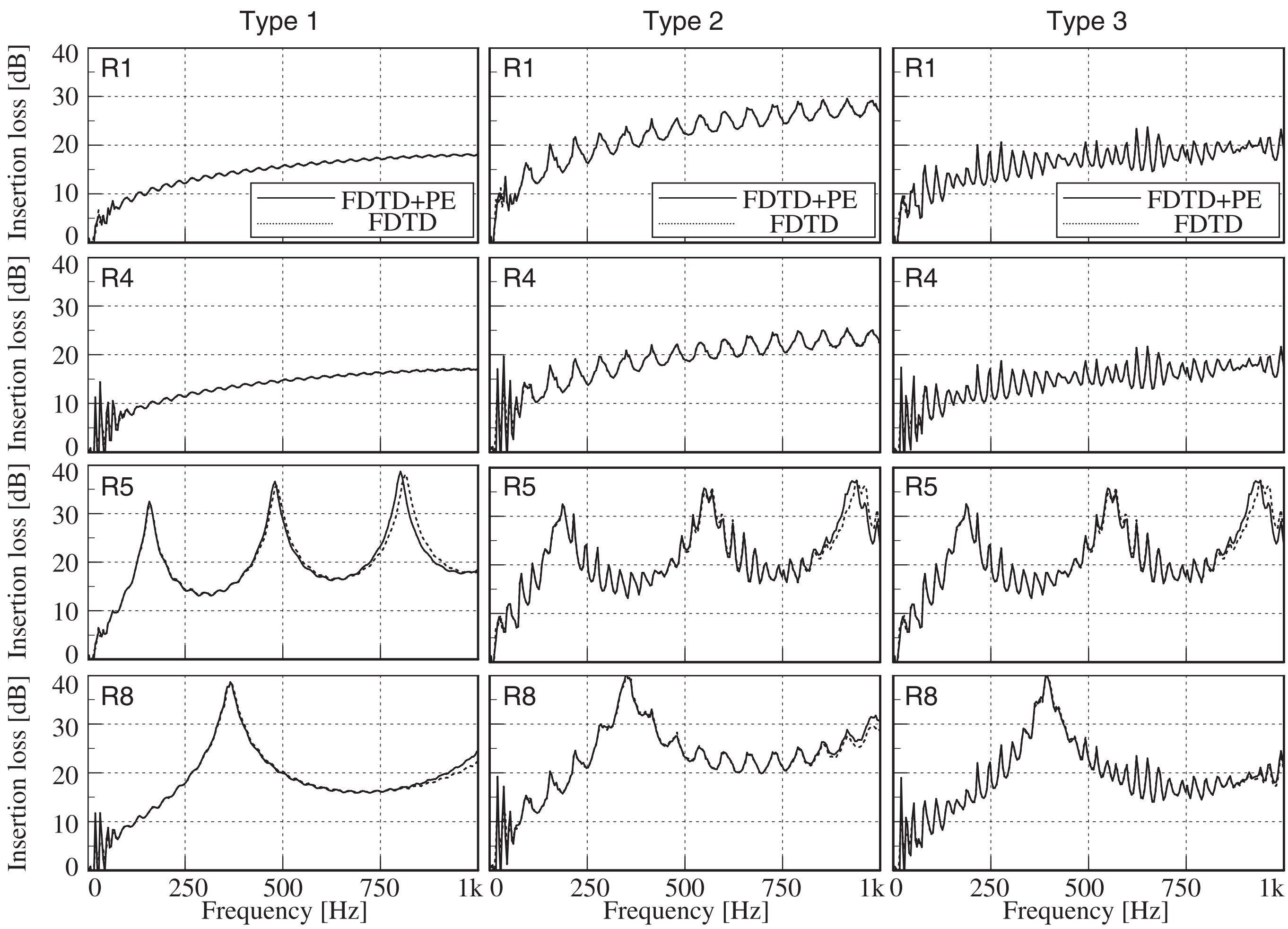

Fig. 5 Sound insertion loss at each receiving point.

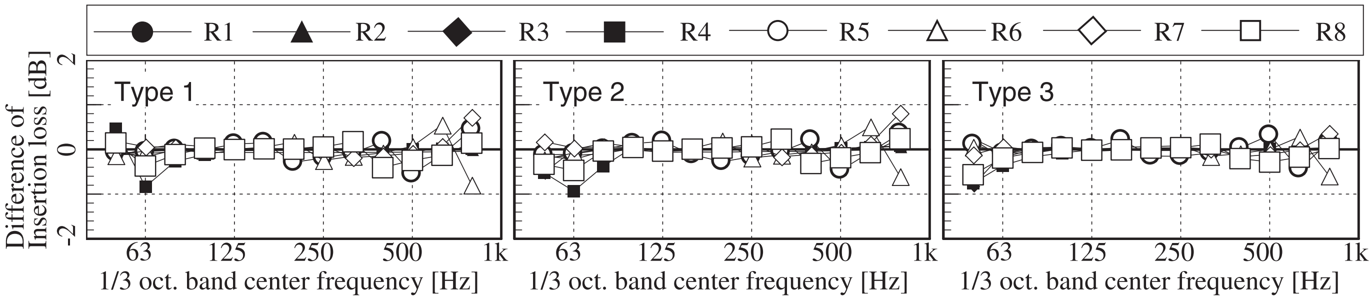

Fig. 6 Differences of sound insertion loss in 1/3 octave band.

calculated by the FDTD method and the impulse response at each receiving point was obtained.

Figure 5 shows the comparison of insertion loss determined by the full FDTD method and the coupled FDTD-PE method. The insertion loss is defined as the level difference between without and with the barrier. It is seen that the results of the coupled method are in fairly good agreement with that of the full FDTD method.

Next, the insertion loss in each 1/3 octave band was calculated by integrating the frequency components included in each band. Figure 6 shows the differences in insertion loss calculated by the coupled method and full FDTD method. Each value shows the level difference calculated by the former result minus the latter one. It is seen that the differences are less than ± 1 dB for each case.

Finally, the computation time and resources are compared. Table 1 shows the calculation time and required memory size for the coupled method and full FDTD method. It can be seen that the load of the computer is markedly reduced in both the calculation time and memory size by coupling the two methods. It is also noted that the required memory size does not increase at all even if further long-distance sound propagation is calculated. For example, when a receiving point is located at 1 km away from the noise barrier, the required memory size of the coupled method is not changed at all, whereas a memory size of approximately 650 MB is necessary in the case of the full FDTD method.

4. Conclusions

In order to predict long-distance outdoor sound propagation, a new calculation method has been developed by coupling the FDTD method and PE method. In this paper, it is found that the calculation accuracy of the proposed method is almost equal to that of the full FDTD method and both the calculation time and required computer memory size of the former are smaller than those of the latter. As future work, the variations of sound propagation characteristics due to the influence of meteorological factors such as temperature and wind speed profiles will be investigated using this developed simulation method.

Table 1 Comparisons of calculation time and required memory size.

		FDTD+PE	FDTD
CPU		Pentium4 2.8 GHz	
Memory size	FDTD:	About 19 MB	About 35 MB
	PE:	About 0.06 MB	
Calculation time		About 1 hour 43 min	About 3 h 20 min
	FDTD:	About 1 h. 35 min	
	FFT:	About 2 min	
	PE:	About 6 min 5 s	

References

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[2] S. Sakamoto, T. Seimiya and T. Tachibana, “Visualization of sound reflection and diffraction using finite difference time domain method,” *Acoust. Sci. & Tech.*, **23**, 34–39 (2002).