Field experiments on the influences of wind speed and direction on outdoor sound propagation over flat ground

Takatoshi Yokota[a], Koichi Makino[a], Kohei Yamamoto[a], Yasuaki Okada[b] and Koichi Yoshihisa[b]

[a]Kobayasi Institute of Physical Research, 3-20-41 Higashi-Motomachi Kokubunji, 185-0022 Tokyo, Japan
[b]Faculty of Science and Technology, Meijo University, 1-501 Shiogamaguchi Tempaku-ku, 468-8502 Nagoya, Japan
t-yokota@kobayasi-riken.or.jp

The influences of wind on outdoor sound propagation are investigated both by field experiments and numerical simulations. At first, measurements of sound propagation at a distance of 130 m were carried out under various wind speed and direction. The relationship between vector wind speed and the variation of sound pressure level has been examined not only for the up/down wind conditions but also for the crosswind conditions. Secondly, the short term sound fluctuations were investigated by the use of a high energy impulsive sound generator and a loud speaker as sound sources. Sound propagation up to 300 m was examined with frequency range from 16 Hz to 4 kHz octave band. Finally, the sound speed profiles in the measurement field were estimated by two methods; one was based on the time interval during the sound propagation from the source to the receivers, the other was based on the wind speed at height of 0.6 m, 1.2 m, 2.4 m and 4.8 m, and the temperature. By using those sound speed profiles, the excess attenuation was calculated by the PE method. The measured and the calculated values have been compared and the methods to estimate the influences due to wind condition have been discussed.

1 Introduction

Outdoor sound propagation is strongly influenced by meteorological conditions and sound pressure level (SPL) at greater distant points from a source varies due to the variation in wind and temperature [1][2]. In general, to consider the influences of wind on outdoor sound propagation, the sound speed profiles estimated based on the vector wind speed have been implemented in the prediction. In this study, the influences of wind on outdoor sound propagation have been investigated through the basic field experiments. Furthermore, the parameters of sound speed profiles assumed in the prediction have been investigated and the prediction results have been compared with measurement results.

2 Dependence on vector wind speed

In the predictions of outdoor sound propagation, the influences of wind direction to sound propagation path have been generally considered by assuming the vector wind speed determined from wind direction and true wind speed as the wind speed in the calculation. In order to examine the influences of vector wind speed on outdoor sound propagation, a series of field experiments were carried out over a large flat asphalt-paved ground under various wind conditions. In the site, the source points were set at the position of every 90 degree on the circumference of 130 m in diameter and microphones were set at the position on the circumference opposite to each source point and at the center position of the circle. As a sound source, a loud speaker was set at a height of 1.0 m above the ground. A 2D-ultrasonic anemometer was also located at the center position of the circle. Figure 1 shows the layout of the equipments in the case that sound propagates from west to east. In each trail, pink noise with a frequency range from 250 Hz to 4 kHz was radiated for 1 minute. At each source position, the test was conducted three times successively.

Figure 2 shows the wind direction, true wind speed and vector wind speed averaged over 1 minute in each trail. In the figure, x-axis shows the number of trial and source position (azimuth orientation). It is seen that the vector wind speed varied from -5 m/s to +5 m/s by changing the source position while wind direction and true wind speed were almost constant. In the analysis, the acoustic signals were processed to obtain averaged octave band sound pressure levels for a second by passing through digital

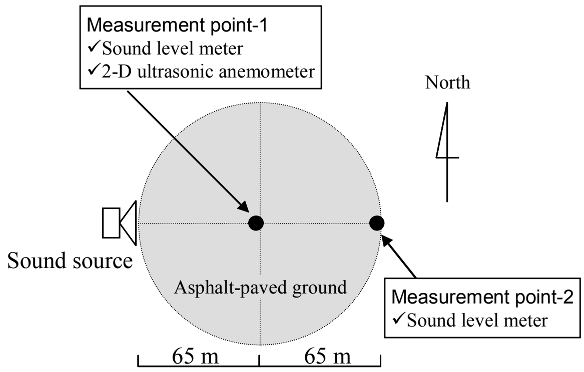

Fig.1 Measurement site.

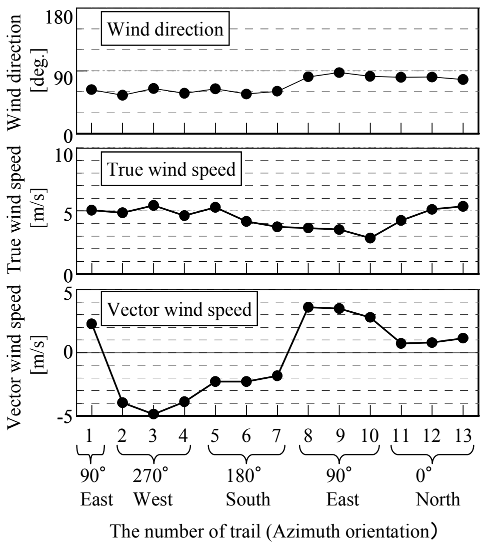

Fig.2 Conditions of wind during the measurement

filters of 250 Hz to 4 kHz bands. The resultant value was corrected for air absorption and the sound attenuation in excess to spherical spreading (excess attenuation) was determined.

Figure 3 shows the measured excess attenuation vs. vector wind. Each plot shows the averaged value for every second. It is seen that the fluctuation of instantaneous levels in each vector wind condition became larger at higher frequencies in upwind conditions. In comparison with the crosswind conditions which the vector wind speed was close to 0 m/s, excess attenuation became larger in upwind conditions and that became smaller in downwind conditions. It indicates that the excess attenuation varies according to the vector wind speed. However, it should be noted that the excess attenuations in crosswind conditions did not approach to 0 dB, especially in higher frequencies.

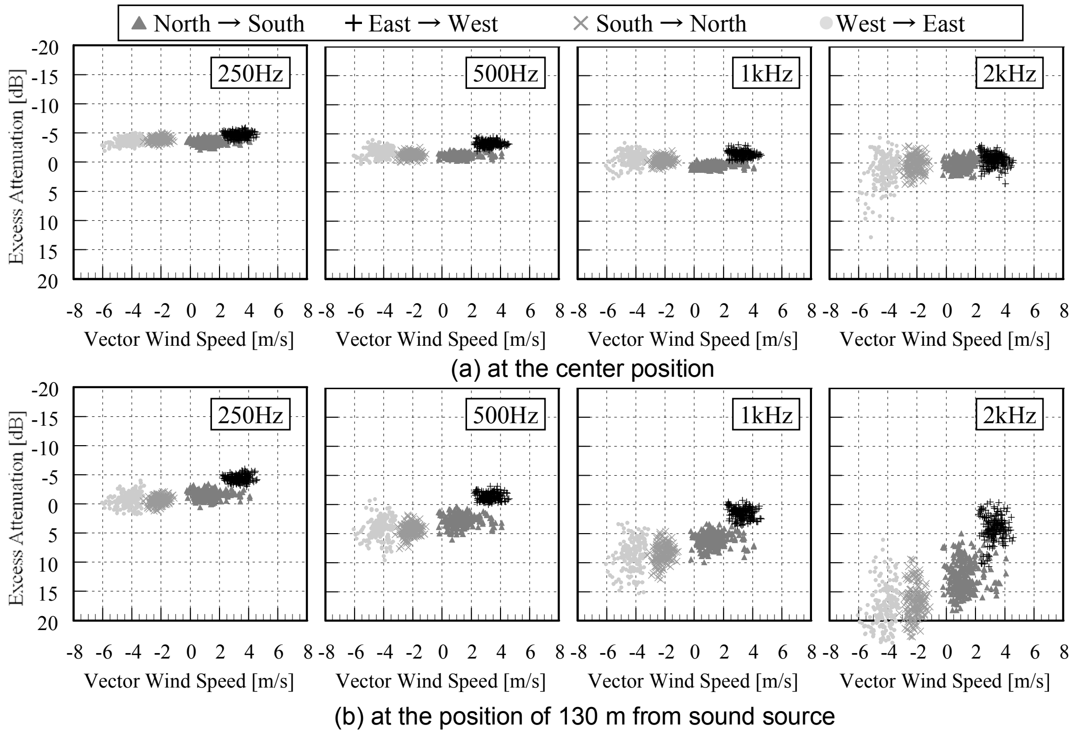

Fig.3 Variation in excess attenuations according to the vector wind speed

3 Variation in frequency characteristics

In order to examine the variation in frequency characteristics of SPL at distant points from a sound source due to the effects of wind, a series of outdoor sound propagation measurements were carried out over asphalt-paved runway and over the grass field in multi-purpose Aerospace Park. The microphone arrangement is shown in Fig. 4. The range of measurement was about 300 m and the source positions were set at the each end of the measurement range. The microphones were arranged at 5, 55, 105, 155, 205 and 305 m from each source position at 1.2 m in height. In order to observe wind speed condition during the measurements, a 2D-ultrasonic anemometer was also set at M3 (M3’) at 1.2 m in height. As a sound source, a high energy impulsive sound generator was used. Figure 5 shows the apparatus of air-explosion type impulse generator which generates a strong impulse when the PET [polyethylene terephthalate] sheet held at the opening of the vinyl chloride tube is broken by piercing with a nail under the condition that the air pressure inside of the tube is set at 3 atm. Figure 6 shows the sound energy level (L_J) of the impulse generator.

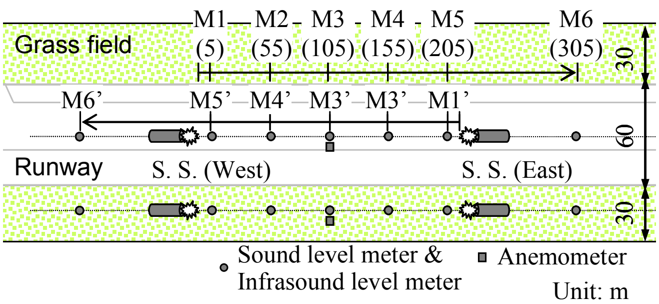

Fig.4 Arrangement of experimental equipments in the measurement site

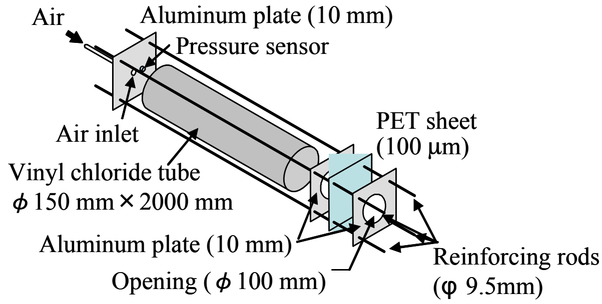

Fig.5 Impulsive sound generator

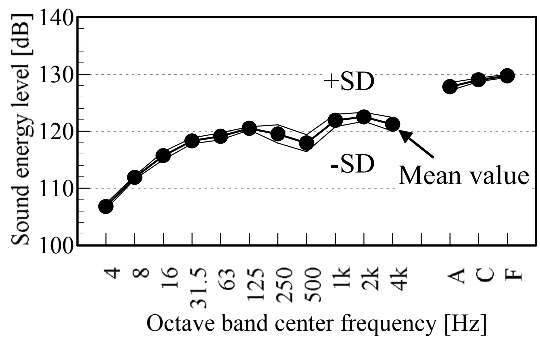

Fig.6 Sound energy level of the impulsive sound generator

Figure 7 shows the sound pressure exposure levels at M3 (M3’) and M5 (M5’) relative to those of M1 (M1’). The values in the explanatory note denote the mean vector wind speed for 1 second when the impulse sound was generated. It is seen that the fluctuation of the relative SPL due to variation in vector wind speed is very small at low frequencies under 63 Hz and that increases with frequency. It is also seen that the frequency in which the fluctuation of SPL is occurred shifts to lower according to the increase in propagation distance. These tendencies clearly indicate that the fluctuations of SPL depend on not only wind speed but also wave length and propagation distance.

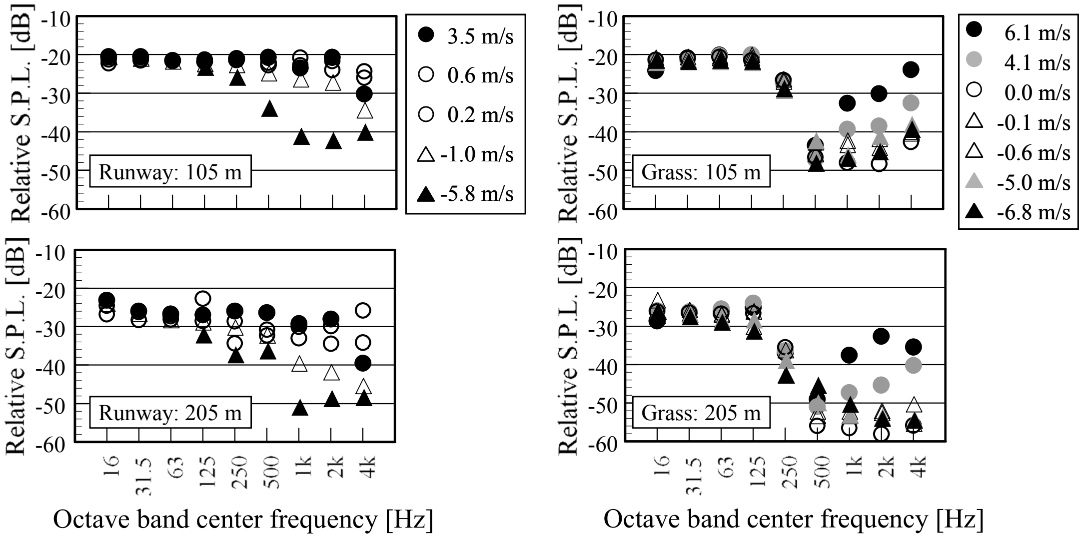

Fig.7 Variation in frequency characteristics at distant points from the sound source due to the effects of wind

4 Comparison between measurements and predictions

4.1 Outline of the measurement

In order to obtain the precise experimental results on variations of SPL due to the effects of meteorology, a series of measurements were carried out at the same field described at section 3. The range of measurement was 300 m and the source positions were set at the each end of the measurement range. The microphones were arranged at 1, 50, 100, 150, 200 and 300 m from each source position at 1.2 m in height. In order to observe wind speed conditions during the measurements of sound propagation, 2D-ultrasonic anemometers were also set at each measurement position at 1.2 m in height except M6 and M6'. At the point of M3 (M3'), microphones and 2D-ultrasonic anemometers were also set at 0.6 m, 1.2 m, 2.4 m and 4.8 m in height, respectively. Figure 8 shows the layout of the equipments. As a sound source, a swept sine signal was emitted from a loud speaker set at 1.0 m in height. Eleven trials were conducted on the runway and 10 trials were made on the grass field. In each trail, the swept sine signal with frequency range from 250 Hz to 4 kHz was radiated 11 times a minute.

Figure 9 shows the averaged vector wind speed for a minute measured at 1.2 m in height of M3 (M3') during each trial. In the figure, solid circles mean the trials carried out on the runway and the open circles mean the trials on the grass field. It is seen that the vector wind speed varies during the series of measurements.

In the analysis, each swept sine response was converted into impulse response and processed to obtain octave band sound pressure exposure levels by passing through digital filters of 250 Hz to 4 kHz bands. The resultant octave band sound pressure exposure levels were averaged and the excess attenuation of each trial was calculated with respect to each frequency.

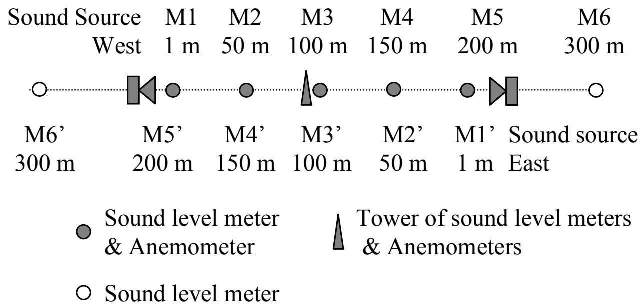

Fig.8 Arrangement of the experimental equipments in the measurement site

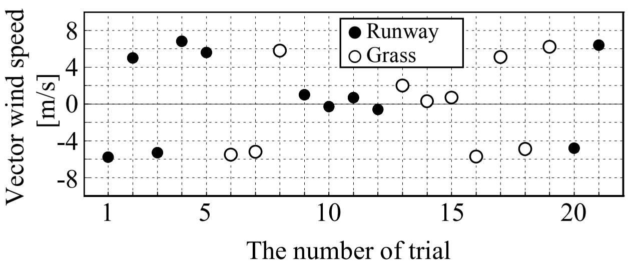

Fig.9 Ground and wind speed conditions of each trial

4.2 Sound speed profiles

The sound speed profile is one of the most significant parameters for the prediction of SPL in outdoor. Ordinarily, sound speed would be estimated based on wind speed and temperature observed at some limited locations. By the method, however, the estimated values might be strongly influenced by the local conditions at each observation point. In order to understand representative sound speed through the sound propagation path, a method to estimate the sound speed based on the time interval of sound propagation from the source to the receivers has been examined. The time interval during the sound propagation was estimated by comparing the time which the peak of each impulse response observed at the point of M1 (M1') and other points. The sound speed obtained for each impulse response was averaged in each trail. Figure 10 shows the estimated sound speed at M3 (M3') and M4 (M4') based on the time interval. In the figure, the estimated values of sound speed based on the vector wind speed and temperature averaged for 1 minute during each trail are also shown. Same tendency between the estimated values by the two methods is seen, whereas the range of variation is a little wider in the latter than the former.

Figure 11 shows examples of the vertical sound speed gradient at M3 (M3') estimated based on the time interval and meteorological observation. It is seen that the gradient of sound speed profiles based on the time interval tend to be smaller than those based on the meteorological observation. By fitting these vertical sound speed profiles to the following equation, roughness length (z_0) was estimated for the runway and the grass field.

$$c(z) = a\ln(1+\frac{z}{z_0}) + c_0 \qquad (1)$$

where z_0 is the roughness length of the ground in meter, a is the gradient of sound speed profile and c_0 is the sound speed at ground-level. As the roughness length of each field, median of the estimated values from 11 profiles for the runway or 10 profiles for the grass field was calculated. Furthermore, the roughness length was also estimated by fitting a large number of measured short time averaged wind speed profiles for every 1 second during all trials to Eq. 2 (the number of profiles: runway 9311, grass 11342).

$$u(z) = a\ln(1+\frac{z}{z_0}) \qquad (2)$$

The estimated values of roughness length of the runway and the grass field by each method were shown in Table 1. It is seen that the values estimated based on the time interval were smaller in both cases of runway and grass field. It means that the sound speed gradient estimated based on the meteorological observation is larger than that based on the time interval.

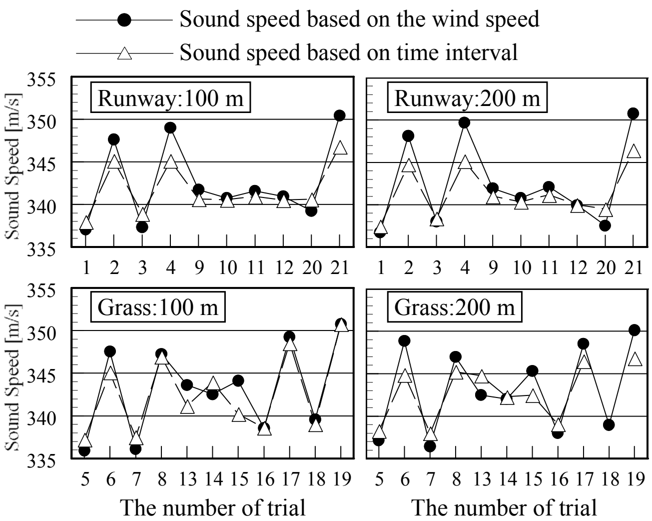

Fig.10 Comparisons of estimated sound speed

Table 1 Estimated roughness length Unit: m

	Roughness length	
	runway	Grass
Time Interval	0.00001	0.00007
Averaged wind speed (1 minute)	0.00067	0.01043
Instantaneous wind speed	0.00030	0.01700

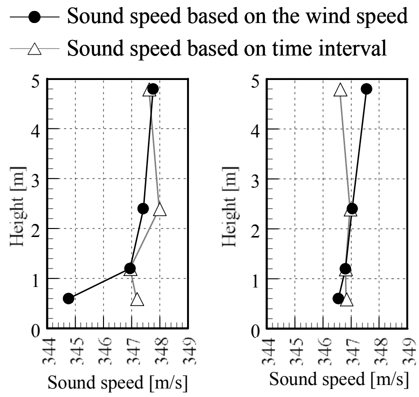

Fig.11 Comparisons of vertical sound speed profiles

4.3 Outline of the prediction

Outdoor sound propagation under the influence of wind in steady state conditions can be calculated by the PE method. For the prediction of the sound pressure level under the influence of time variation in wind speed, the weighted mean sound pressure level ($\overline{L_p}$) at the receiving points was calculated using the results of the PE calculation and the relative frequencies of the histogram prepared from the observed instantaneous vector wind speed during each trial [3]. The PE calculation was carried out for each 1/12 octave band center frequency and the summation of the 12 results was calculated for each octave band. As the boundary conditions of grounds, effective flow resistivity of 20000 kPa·s/m^2 was assumed for the asphalt runway and 200 kPa·s/m^2 was assumed for the grass field. The value for grass field was estimated based on the measurement results of sound propagation under calm condition.

4.4 Comparison of excess attenuation

Figure 12 shows the excess attenuation obtained by measurements and calculations. The values in the explanatory note denote the average vector wind speed for 1 minute measured at the M3 (M3') at 1.2 m in height when the swept sine signals were generated. In the Calculation-1, the values of roughness length estimated from the instantaneous wind speed profiles shown in Table 1 were used and the values estimated from the time interval were assumed in the Calculation-2. In the calculations, instantaneous vector wind speed measured at all positions where the ultrasonic anemometers were set at 1.2 m in height during each trial was used as samples to obtain the relative frequencies of the vector wind speed histogram. It is seen in both measurement and calculation results that the variation of excess attenuation gradually became larger with increasing propagation distance. In the measurement, the excess attenuation varied from about -10 to 25 dB according to the variation in wind speed in both cases of sound propagation over the runway and the grass field. In comparison among measurement and calculations, it is seen that the calculated excess attenuation is good agreement with that of measurement in the downwind condition in both cases of sound propagation over the runway and the grass field. It is also seen that the results of Calculation-2 were more similar to the measurement results than those of the Calculation-1 in the cases of upwind conditions.

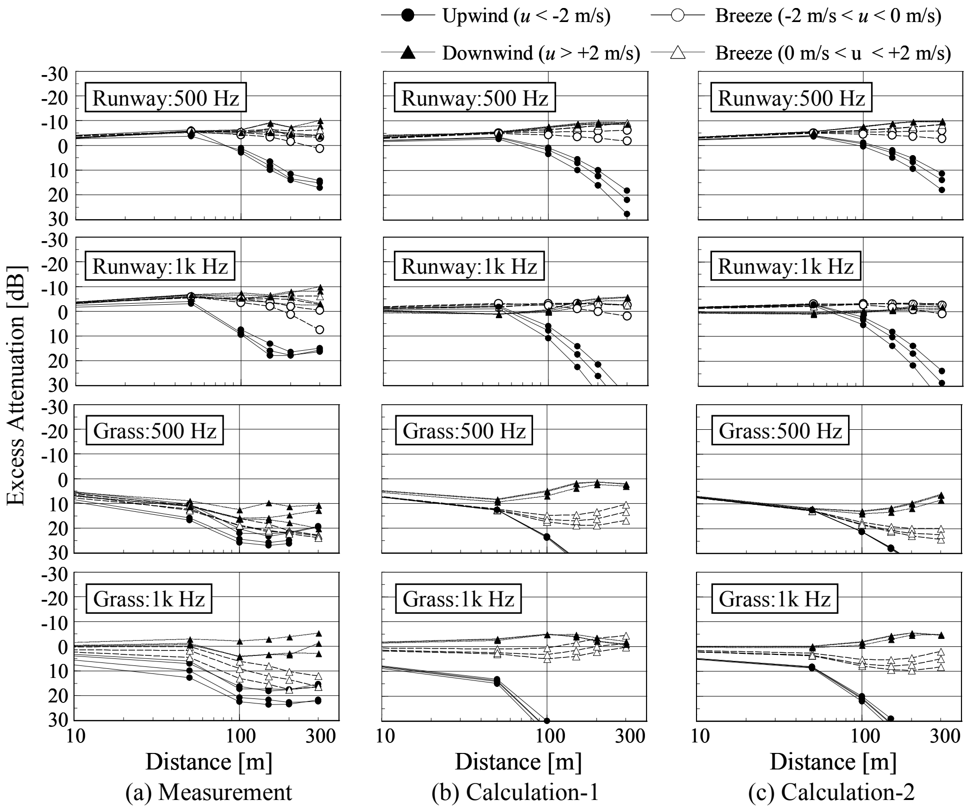

Fig.12 Comparisons of excess attenuation

Finally, excess attenuations over the runway were plotted in terms of the normalized distance obtained by dividing the sound propagation distance by wave length. Figure 13 shows the results of measurement and Calculation-1. In downwind conditions, the excess attenuation was distributed around -5 dB regardless the normalized distance. In upwind conditions, the excess attenuations became larger with increasing the normalized distance. In comparison between the measurement and the calculation, differences are clearly seen in the range above 1000 of normalized distance in upwind conditions. The measurement results became close to about 20 dB, whereas the calculation results decreased with the normalized distance.

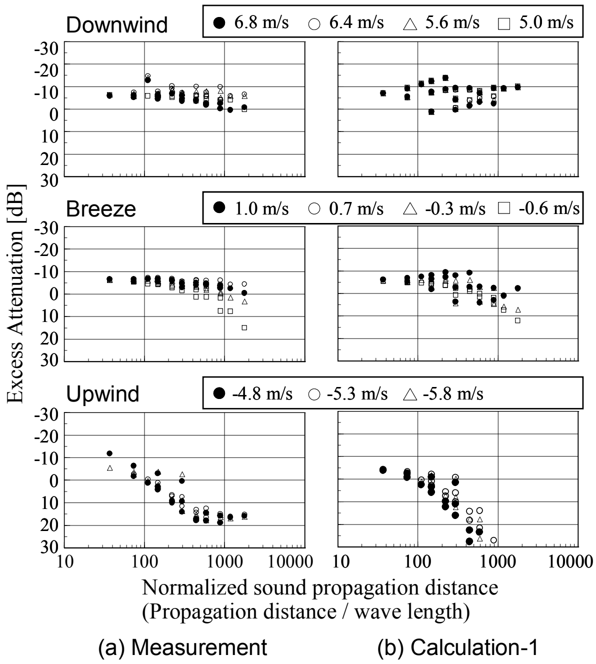

Fig.13 Plot of excess attenuations against normalized sound propagation distance

5 Conclusions

In order to investigate the influences of wind on outdoor sound propagation, a series of field experiments were carried out under a various wind conditions. In the experiment to investigate the influences of wind direction to sound propagation path, it has been confirmed that SPL at remote distance varies according to the vector wind speed including in crosswind conditions. In the experiment by using impulsive source with wideband frequency components, it has also been confirmed that the fluctuations of SPL depend on not only vector wind speed but also wave length and propagation distance. From the comparisons between the measurement and numerical simulation, the weighted mean sound pressure levels determined by the PE calculation show relatively good agreement with measurement results in the cases that the roughness length was estimated from vertical sound speed profiles based on the time interval during the sound propagation from a source to a receiver. It has been also suggested that the variations in SPL due to the influences of wind can be discussed based on the vector wind speed and normalized sound propagation distance in the cases of sound propagation over hard ground.

References

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