6th International Meeting
on
Wind Turbine Noise
Glasgow 20-23 April 2015

Wind Noise Estimation Functions for Low Frequency Sound Measurement in Natural Wind at Different Topography Types

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Summary

According to previous reports, field measurements of outdoor noise are highly affected by weather. Especially, the field measurement of low frequency sound is significantly affected by natural wind as natural wind always fluctuates in random direction. Thus, it is impossible to measure low frequency sound in field on a calm day at all times. The secondary wind screen is suggested for reducing effect of the wind on the noise measurement of the wind farm. However, the commercial secondary wind screen generates uncertainty on reducing wind noise, as the characteristics of the secondary wind screen have not been regulated. To solve this problem, we have developed a method to measure low frequency sound while estimating wind noise in real time by combining a supersonic anemometer with a low frequency sound level meter. In this method, we observed the wind noise properties which are measured by low frequency sound level meter and developed a regression equation of wind noise in 1/3 octave band, then combined this algorithm with level meter. In this study, we reported collected data on field and the regression coefficients for the wind noise estimation at different topography types with different aerodynamic roughness. Further, the results of wind noise effects for every wind velocity on elevated road derived from traffic noise were presented. We assume that this wind noise estimation could be applicable for measurement of low frequency sound pressure in wind turbine.

1. Introduction

Low frequency sound is usually measured outdoors, but measured data contain uncertainty unless impact of wind noise on the measuring microphone is evaluated. Therefore, to fix this problem we have developed a method for measurement of low frequency sound in natural wind, in which impact of wind noise in real time is considered by combining a supersonic anemometer with a low frequency sound level meter. As the result, we have been able to more accurately estimate wind noise level. Presently, we have tried to develop a method for estimation of wind noise targeted at the low frequency sound from elevated road, and we are going to study wind noise regression equation in strong wind such as wind farm in the future.

Two phenomena are considered having effect on the measurement as wind noise when data is received by microphone. One is the perturbation of pressure caused by vortex shedding, the other is the turbulence flow caused by ground surface layer and roughness. This is also fluctuation of pressure with the random fluctuation of wind velocity. Because the microphone is pressure sensor, it also measure pressure fluctuation in wind. On the frequency band called infrasonic sound, the pressure fluctuation in approach flow usually causes problem.

In the method developed by this research, we define that output level by the wind is wind noise level. Therefore, if the measurement systems are different, wind noise levels are different. In this measurement method, the microphone is equipped with a wind screen, which is set on the microphone stand. If wind screen or microphone is changed, we modify function for estimation of the measuring system.

Japan Industrial Standard - JIS C1400-11 "Wind turbine generator systems: Acoustic noise measurement techniques " has defined the method for installation of microphone, as shown in Fig.1. Though the reduction of wind noise seems to be effective, in the ultra-low frequency sound range, the effect is unknown. Further, the method of installing a microphone on the ground is unusual as measurement techniques of environmental noise. In this study, the microphone was set on its tripod. One more reason that our microphone installation method has been adopted is:

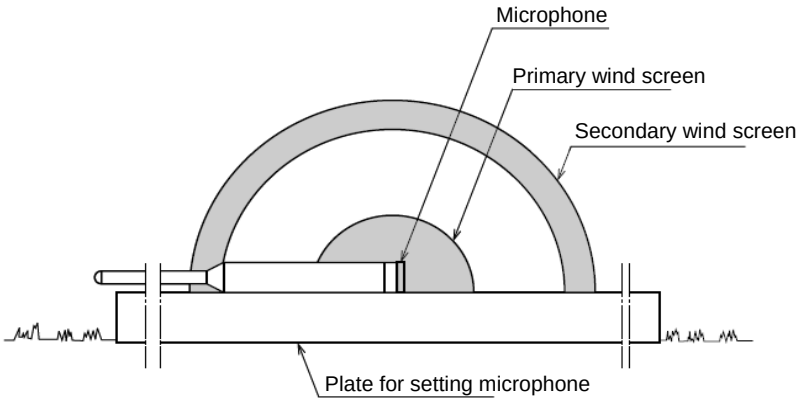


Fig.1 Secondary wind screen(JIS C1400-11)

Fig.2 shows vertical profiles of wind velocity and wind pressure fluctuations which are obtained by DNS (Direct Numerical Simulation) calculation of a turbulent boundary layer. Value of wind pressure perturbation on the ground does not return to zero even though wind velocity is zero. This leads to a thought that influence of wind noise is the same no matter how the microphone is installed. For example, if mean velocity is 2 m/s at the elevation of 2 m, RMS value of pressure fluctuation is 0.5 N/m^2, and it is 88dB for sound pressure level. It is clear that wind noise causes uncertainty in measurement of low frequency sound.

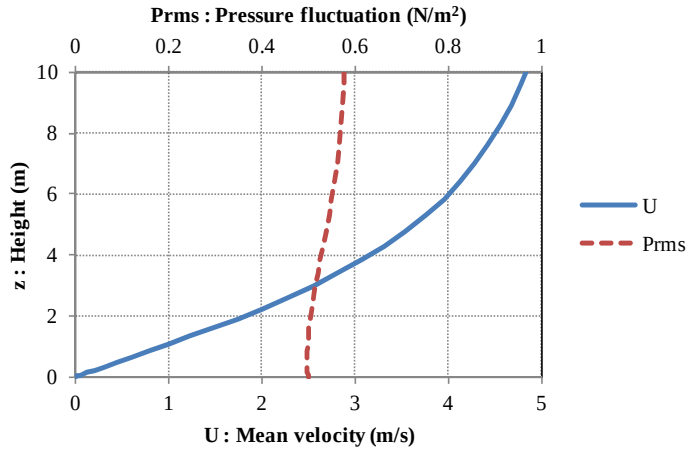


Fig.2 Vertical profiles of wind velocity and wind pressure fluctuation

2. Definitions of wind parameters

The definitions for mean wind velocity and turbulence intensity are developed as follows: Regression function of wind noise level is introduced using U, u_0, Iu parameters, shown in equations (1) and (2).

$$U = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

$$u_0 = \frac{1}{N}\sum_{i=1}^{N}\sqrt{(u_{(i)}^2 + v_{(i)}^2 + w_{(i)}^2)} = \frac{1}{N}\sum_{i=1}^{N} u_{scalar(i)} \qquad (1)$$

$$Iu = \frac{\sigma_u}{u_0} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_{scalar(i)} - u_0)^2}}{u_0} \qquad (2)$$

Because the output of total level is decided by the pressure of the target sound and the pressure of the wind, the equation (3) is developed.

$$Pout = Psound + Pwind = \rho c V + Cp\frac{1}{2}\rho U^2 \qquad (3)$$

where, ρ :density of air; c : sound speed; V : oscillation speed of air particle; Cp : correction coefficient (non-dimensional); U : wind velocity (measurement data).

When the pressure of wind action is expressed in dB, it follows that

$$Lwind[dB] = 20\log_{10}\frac{Cp\frac{1}{2}\rho U^2}{P_0}$$

$$= 20\log_{10} Cp + 20\log_{10} U^2 + 20\log_{10}\frac{\frac{1}{2}\rho}{P_0} \qquad (4)$$

Where P_0 is 20 μPa.

In this equation, first term is regarded as the function of the frequency, and the last term is a constant term unrelated to the wind velocity. The calculation of wind velocity must consider the fluctuation component $\tilde{u}$, thus

$$U = u_0 + \tilde{u} \qquad (5)$$

From equation (1), (2), (3), (4) and (5), it is interpolates that

$$Lwind[dB] = 20\log_{10} C_p(f) + 20\log_{10}(1+Iu)^2 + 20\log_{10} u_0{}^2 + \Delta \qquad (6)$$

Where, $\Delta = 20\log_{10}\frac{\rho}{2P_0}$.

Finally, the regression function is developed as follows:

$$Lwind(f, Iu, u_0) = A(f) + B(f)\cdot\log_{10}(1+Iu)^2 + C(f)\log_{10} u_0{}^2 \qquad (7)$$

It is understood that from measured Lwind and turbulent intensity and the mean wind velocity, the coefficients (A, B, and C) every 1/3 octave band for regression function (7) are able to be determined by using the measurement data of the time history.

3. Applying the regression function to the measurement system

3.1 Measurement system

We have developed a wind noise level meter as shown in Fig.7. This measuring system has the following functions and features.

1) Measuring low frequency sound as same as ordinary sound level meter
   The same as the low frequency level meter, microphone, level meter, and storing system in 1/3oct.band installed in the system are manufactured by company Aco.

2) Observing the time history of wind velocity components in pedestrian-level
   The Sonic Corporation's anemometer installed in the system is an ultrasonic anemometer, which can measure two components or three components of wind velocity.

3) Estimation of low frequency wind noise simultaneously
   Using the wind noise regression functions installed in the level meter, it is possible to estimate the wind noise which is acting on the microphone simultaneously.

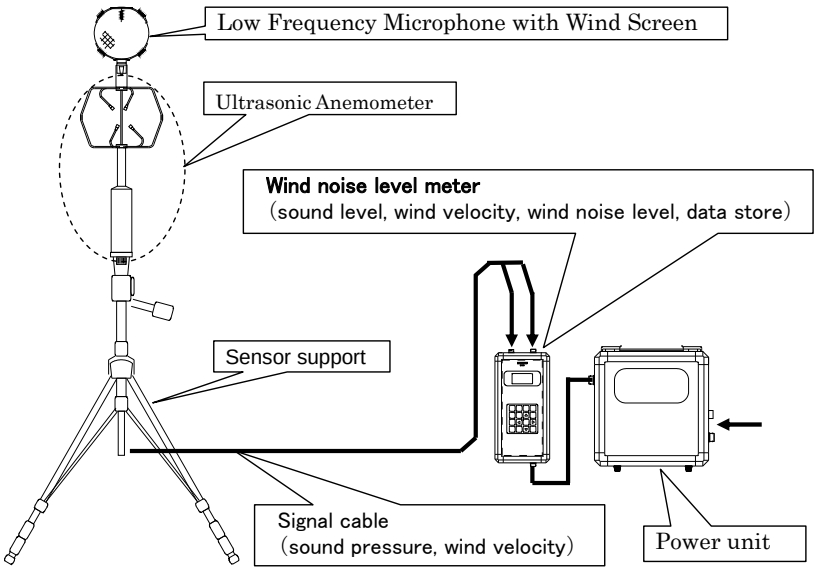


Fig.3 Wind noise level meter

Picture 1 Wind noise level meter

3.2 Measurement sites of wind noise

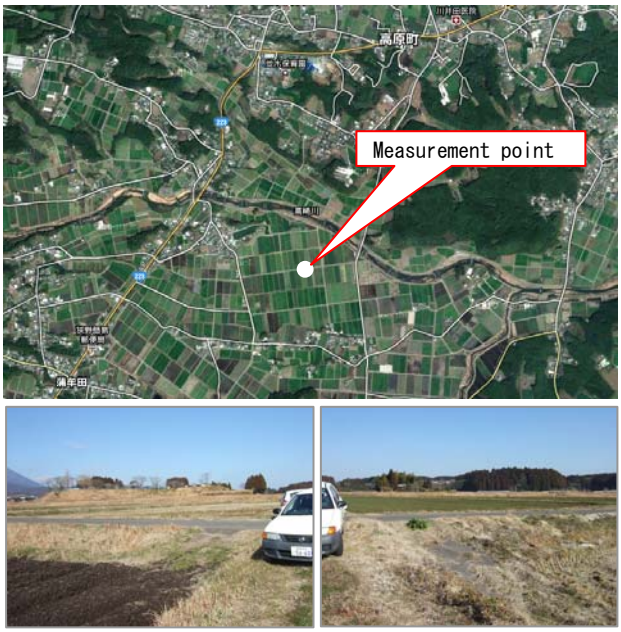
It's requested that the site at which field data of wind noise is measured must be very quiet. If it's possible, the back ground noise level at a quiet moment is approximately 30 dB. It is expected that the wind blows moderately on measuring days on the selected site. Several candidate sites were selected and much data was stored from such view point.

It was assumed that a relation between the wind velocity of the ground-surface boundary layer and pressure fluctuation receives influence from the aerodynamic roughness in wind engineering. Therefore, we selected several sites at which aerodynamic roughness was different. The selected sites are shown in Pictures (2), (3), (4), and (5). In Japan, types of topography with different aerodynamic roughness are classified into 4 categories.

Site A located at the centre of the drained land, and rice field spreads as far as we can see belongs to category I**.** Site B is residential area in Akita-shi suburb and is called category III. Site C and site D belong to category II, and the back ground noise at night will be approximately 30 dB on both sites. On the site of category IV-urban area, the back ground noise level doesn't become low at night. Therefore, we decided not to measure on the sites of category IV (urban area).

Picture 2 A)Hachirougata,AkitaPrefecture

Picture 3 B) Residential area in Akita-city suburb



Picture 4 C)Nihon university, Chiba Prefecture

Picture 5 D)Takaharu-cho, Miyazaki Prefecture

3.3 Results of regression analysis

The results of multi regression analysis of 1/3 octave band based on measuring data of wind noise on each site is shown in Fig.4. The regression coefficients of site C and site D are similar, but those of site B are likely different from site A. It is thought that the estimation function is different depending on aerodynamic roughness.

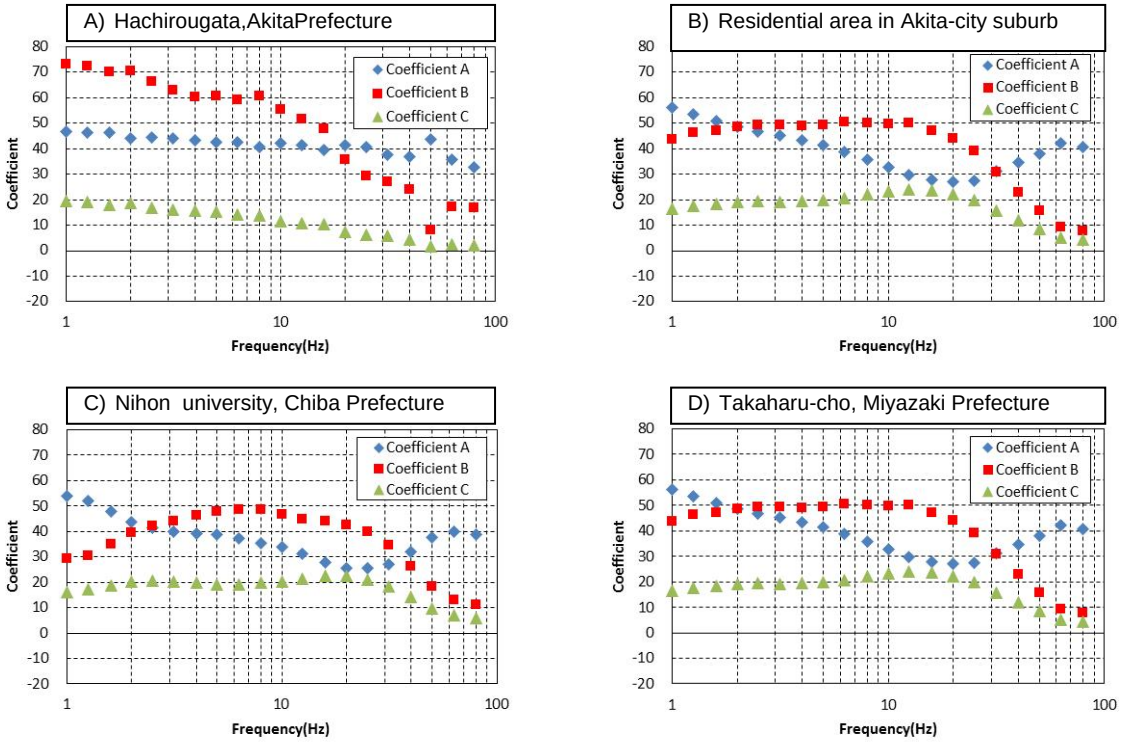


Fig.4 The result of multi regression analysis of 1/3 octave band based on measuring data of wind noise on each site

4. Example of application to low frequency noise of elevated road

The study case that applies this measurement method to the low frequency sound radiated from elevated road is introduced. Equivalent continuous A-weighted sound pressure level is usually used for the evaluation of the road traffic noise. We have used Leq for 10 minutes of 1/3 octave band as the similar evaluation. According to the histogram of mean wind velocity (see Fig.5A), when it is nearly calm, wind noise estimation level is low. Then, the SN ratio is high enough for frequency in the nearly first mode of the elevated road (around 2.5Hz -4.0Hz). In other words, this measurement level doesn't receive any influence of wind noise, so it is considered as a correct measurement level of the target sound.

Fig.6B shows the comparison results of wind noise estimation level and target sound, when it is relatively windy. At the moment the mean wind velocity is approximately 3m/s, the O.A. level and 1/3 octave band level of the 2.5Hz and the 4Hz are influenced by the wind noise. When it becomes more windy, and the mean wind velocity is approximately 7m/s (Fig.5C), the wind noise estimation level of O.A. is higher than the level of the target sound. The SN ratio of 1/3 octave band over 12.5Hz is the sufficiently high level.

The case indicated above is the study case in which Leq for 10 minutes analysed low frequency sound in elevated road by 1/3 octave band, but the target sound and wind noise are non-regular phenomena. To accurately measuring the target sound at the instantaneous peak level, it is necessary to evaluate the wind noise in real time. For example, we should delete measured data which has low SN ratio.

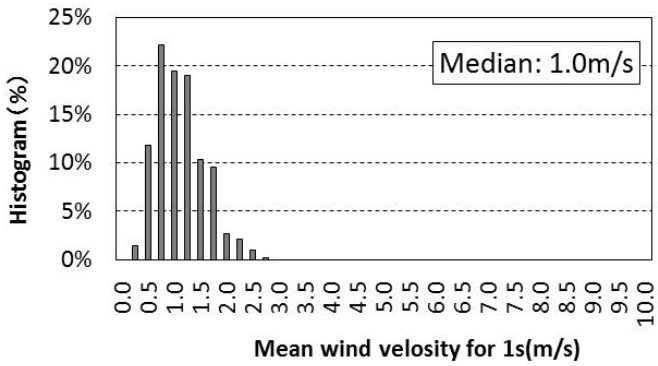


Fig.5A Histogram of mean wind velocity for 1s

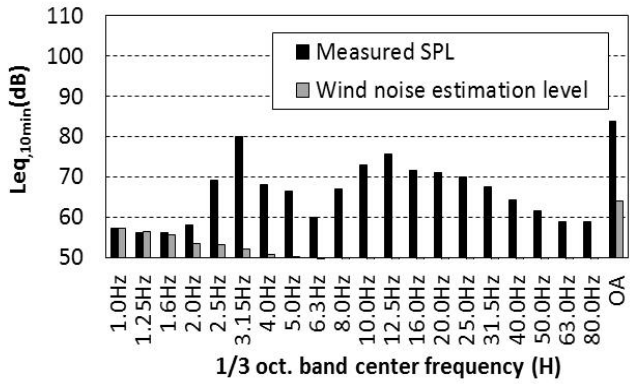


Fig.6A comparison result of wind noise estimation level and target sound

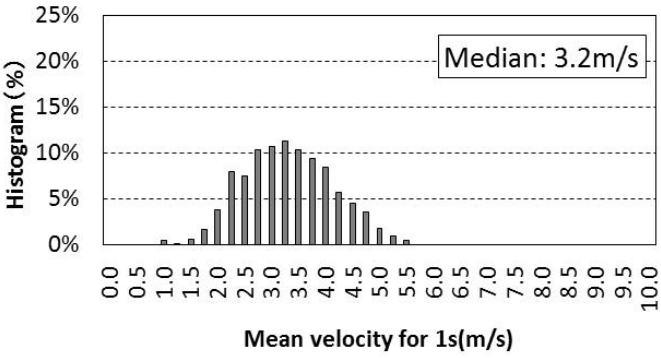


Fig.5B Histogram of mean wind velocity for 1s

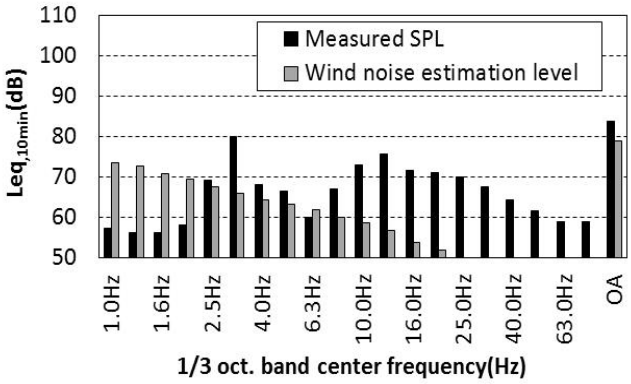


Fig.6B comparison result of wind noise estimation level and target sound

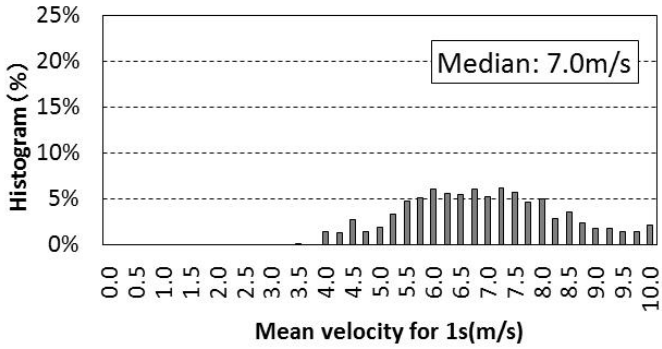


Fig.5C Histogram of mean wind velocity for 1s

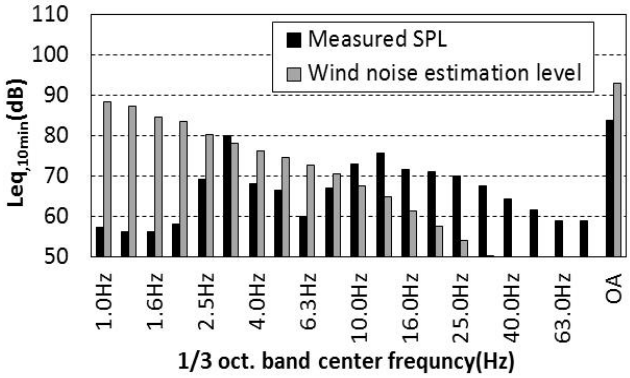


Fig.6C comparison result of wind noise estimation level and target sound

5. Conclusions

We reported collected data on field and the regression coefficients for the wind noise estimation at different types of topography for aerodynamic roughness. In addition, the results of wind noise effects for every wind velocity on elevated road derived traffic noise were shown. We have pointed out the importance of estimating wind noise in real time. More field data are going to be stored to extent its application to wind farm from now on.

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