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Improvement of regression analysis on wind noise effects for low frequency sound measuring in natural wind

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Summary

It is well known that the outdoor measurement of low frequency sound is affected very much by the surrounding natural wind. Low frequency sound should be measured when there is no wind. But actually there are cases that we must measure even if the wind is blowing. We'd like to be able to distinguish the wind noise effect appropriately and to measure low frequency sound. We have investigated the method to evaluate wind noise effects by the regression function. As the previous work, the definition of wind noise was shown, and wind tunnel test and outdoor experiment were conducted. And we made it clear that the wind noise was affected by frequency of sound, turbulence intensity and mean wind velocity. In the present paper, we present regression functions by natural wind based on the sound

measurement at outdoor sites. In addition, we targeted low frequency sound caused by a viaduct of expressway for the evaluation, and we tried the estimation of wind noise effect using the regression function. We assume that this wind noise estimation is the example that is available for measurement of low frequency sound pressure in wind turbine.

1. Introduction

Supposing that both sound pressure (target sound ; [Pa]) and fluctuation wind pressure (wind noise ; [Pa]) are acting on the microphone with random state of pressure phase, the output signal ([Pa]) from the microphone contains both time sequence of each pressure. This relationship is described in root mean square values as follows, where it is possible to treat as ordinary back ground noise.

$$Pout = Psound + Pwind = \rho c V + Cw \frac{1}{2} \rho u^2 \tag{1}$$

where ρ ; density of air, c ; sound speed, V ; oscillation speed of air particle, Cw ; correction coefficient (non dimensional), u ; wind velocity (possible to measure).
Equation (1) is written in Pascal dimension, and these terms are rewritten in dimension dB by employing the reference pressure P_0 (20μPa).

$$Lout[dB] = 20\log_{10} \frac{Pout}{P_0} \tag{2}$$

$$Lsound[dB] = 20\log_{10} \frac{Psound}{P_0} \tag{3}$$

$$Lwind[dB] = 20\log_{10} \frac{Pwind}{P_0} \tag{4}$$

In the previous paper[5], we proposed equation 5 as regression function. The target sound is low frequency sound caused by a viaduct of expressway. We are collecting field data more and improving regression function for estimation of the wind noise effect now.

$$Lwind = A + B \cdot (\log f)^{3/2} \tag{5}$$

$$A = c_a + d_a \cdot \sqrt{Iu}\,, \qquad B = c_b + d_b \cdot \sqrt{Iu}$$

$$c_a = c_{a0} + c_{a1} \cdot u_0 + c_{a2} \cdot u_0{}^2 \qquad d_a = d_{a0} + d_{a1} \cdot u_0$$

$$c_b = c_{b0} + c_{b1} \cdot u_0 \qquad d_b = d_{b0} + d_{b1} \cdot u_0$$

2. Concept

In past investigation[1-5] of regression function, we accumulated field data and tried proposition of regression function form corresponding to measured SPL. However, we should originally investigate regression function in consideration of component of

wind noise. We show following equation based on such thought. We try the improvement of the regression function in consideration of equation 6.

$$Lwind = 20\log_{10} C_p(f) + 20\log_{10}(1+Iu)^2 + 20\log_{10} U_0{}^2 + \Delta \qquad (6)$$

The equation is composed of function Cp which assumes parameter of frequency, turbulence intensity Iu, mean wind velocity Uo. We assume the following equation by considering coefficient corresponding to measured SPL (in natural wind) for equation 6.

$$Lwind = A \cdot \log_{10}(f) + B \cdot \log_{10}(1+Iu)^2 + C\log_{10} U_0{}^2 + D(const.) \quad (7)$$

We can set these coefficients of regression function by multiple regression analysis. We decided to set the regression coefficients as 1/3 octave band in parameter f to estimate the wind noise effect more exactly in this report.

$$Lwind = B' \cdot \log_{10}(1+Iu)^2 + C'\log_{10} U_0{}^2 + D'(const.) \qquad (8)$$

Estimation of wind noise will be performed with function form based on the consideration of component of wind noise. Coefficient notations are rewrote and shown following. We can get regression coefficient A,B,C by multiple regression analysis.

$$Lwind = A + B \cdot \log(1+Iu)^2 + C \cdot \log u_0^2 \qquad (9)$$

3. Measurement

3.1 Measurement field We acquire data for investigation of regression function in the field which is very quiet and without obstacle to estimate the wind noise. As measurement Field, we chose Hachirogata in Akita. Picture1 shows the measurement location.

Picture 1 Measurement field (Hachirogata in Akita)

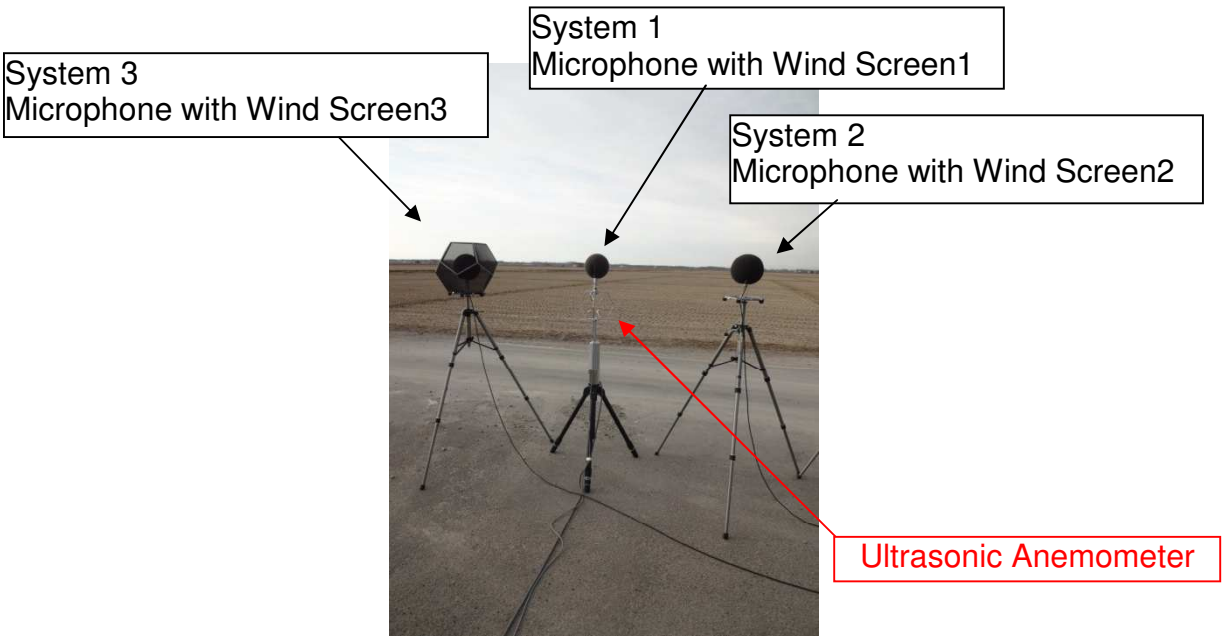
3.2 Wind noise effect of regression functions by different method We make regression function of wind noise by two methods and estimate Lwind, and compare the relations with measured SPL.

- Method1: previous method by equation 5
- Method2: new method by equation 9

3.3 Estimation of Lwind by three measurement systems The regression coefficients of Lwind vary according to measurement system, but the estimation of Lwind is possible. We try estimation by regression coefficients of 3 measurement systems following.

- System1: Microphone with wind screen
- System2: Microphone with another wind screen
- System3: Microphone with another wind screen and Tachibana's wind screen[6]

Picture 2 shows each system. We set three microphones of such a condition near the anemometer, and acquired field data. And we try getting regression coefficients for each microphone. In addition, we confirm difference of regression coefficients for three systems and try the estimation of Lwind.



Picture 2 Measurement microphones

4. Results

4.1 Result of mean wind velocity for one second Fig.1 shows time history of mean wind velocity for one second. The mean wind velocity was measured in the range from 1m/s to 5m/s approximately. Then, we could measure wind noise in the range that we assumed.

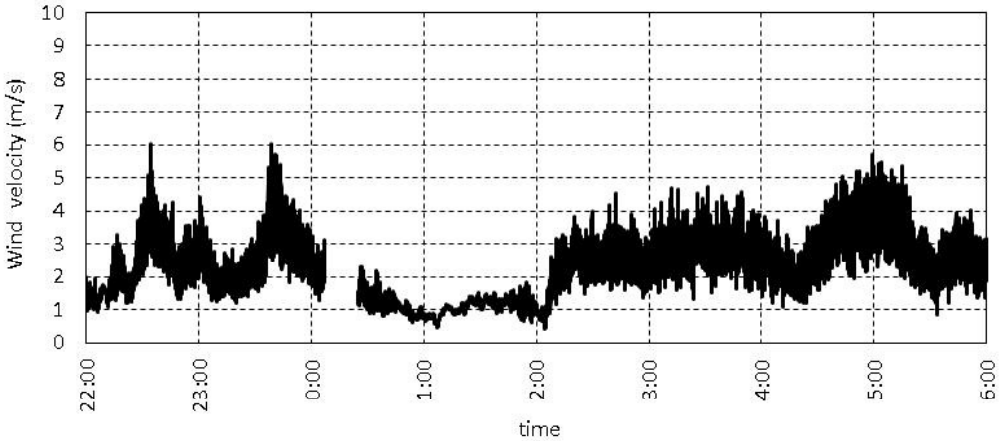


Fig.1 Time history of scalar wind velocity u_0

4.2 Regression functions by different methods

1) Regression function by previous method

Regression function by method 1 are shown following. Fig.2 shows regression coefficient A,B for turbulence Intensity (Method 1).

$$Lwind = A + B \cdot (\log f)^{3/2} \tag{5}$$

$$A = c_a + d_a \cdot \sqrt{Iu}\,, \qquad B = c_b + d_b \cdot \sqrt{Iu}$$

$$c_a = 15.790 + 27.066u_0 - 2.629u_0^{\ 2} \qquad d_a = 5.687 - 1.197u_0$$

$$c_b = -13.296 - 2.236u_0 \qquad d_b = -3.771 + 1.098u_0$$

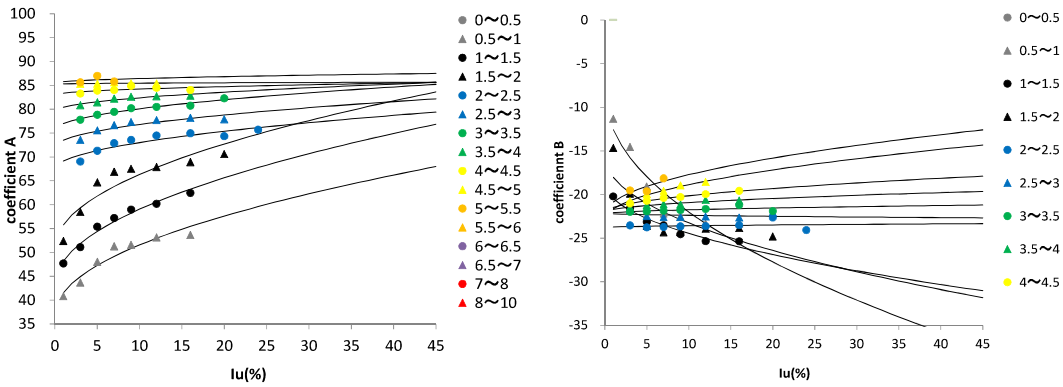


Fig.2 Regression coefficient A,B for Turbulence Intensity (Method 1)

2) Regression function by new method

Regression function by method 2 are shown following. Table 1 shows regression coefficients (Method 2)

$$Lwind = A + B \cdot \log(1 + Iu)^2 + C \cdot \log u_0^2 \tag{9}$$

Table 1 Regression coefficients by method 2

Method 2

frequency(Hz)	coefficient A	coefficient B	coefficient C
1	49.8	69.0	24.1
1.25	48.0	72.6	25.6
1.6	45.5	71.3	27.2
2	43.3	72.1	28.1
2.5	41.1	69.6	28.5
3.15	39.5	67.2	27.6
4	38.0	65.0	26.4
5	35.7	65.1	26.4
6.3	34.2	57.5	25.9
8	33.5	43.3	24.2
10	34.9	23.3	20.7
12.5	33.0	14.8	19.4
16	31.7	5.0	16.4
20	34.3	−9.0	11.6
25	33.2	−15.9	9.3
31.5	33.1	−21.0	6.5
40	31.4	−21.3	5.9
50	31.0	−15.9	4.5
63	28.6	−8.0	4.8
80	22.6	2.5	8.1

3) Comparison of Lwind by regression function of different methods

We compare estimated Lwind by regression function of different methods with measured SPL. It was chosen the time that mean wind velocity was approximately 3m/s. Fig.3 shows time history and percentage of wind velocity in the time domain. Fig.4 shows comparison between estimated Lwind and measured SPL (time history) by regression function of different methods. In addition, Fig.5 shows the result for $Leq_{,10min.}$ Fig.6 shows relationship between estimated Lwind and measured SPL. Estimated Lwind in time history, $Leg_{,10min.}$, Relatiponship between estimated Lwind and measured SPL are similar to measured SPL. As a result, we think that regression function by method 2 in consideration of component of wind noise is better.

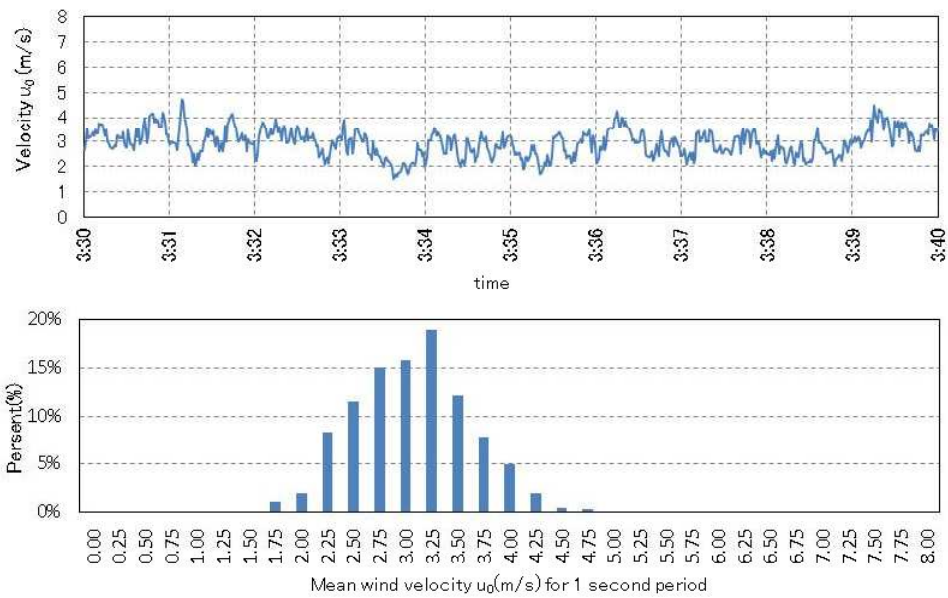


Fig.3 Time history and percentage in the time domain of scalar wind velocity

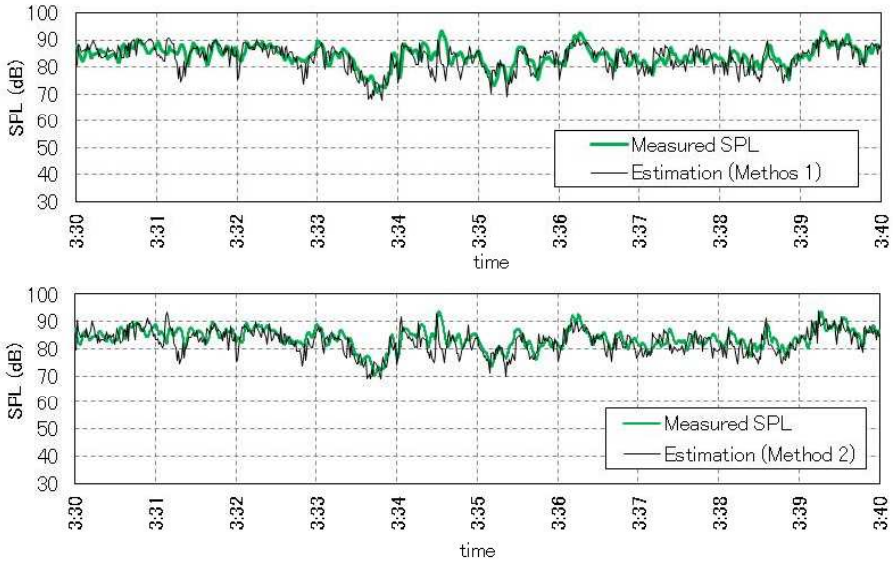


Fig.4 Comparison between estimated Lwind and measured SPL (time history)

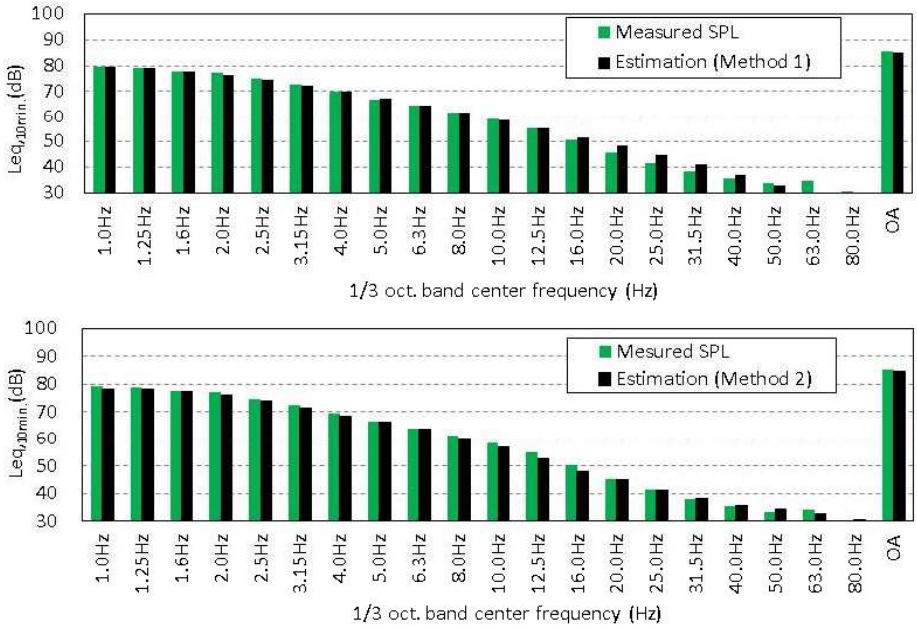


Fig.5 $Leq_{,10min.}$ for 1/3 oct. bamd

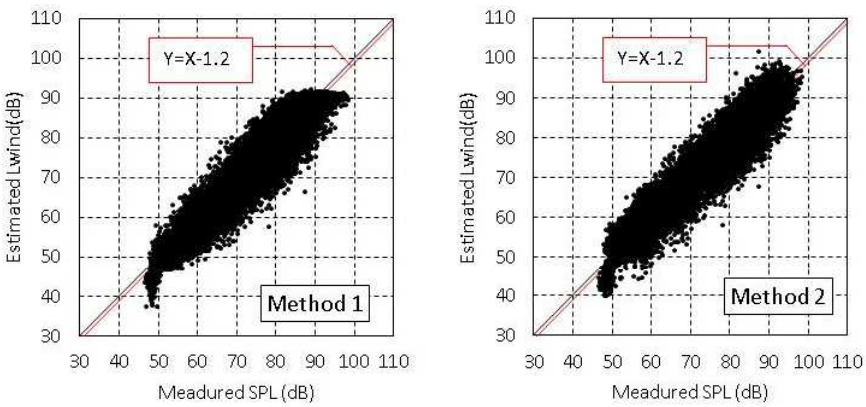


Fig.6 Relationship between estimated Lwind and measured SPL

4.3 Regression coefficients by different system Table 2 shows regression coefficients by three different systems. Fig.7 shows frequency characteristics by regression functions (Iu=0.2). Characteristics to be affected by the increase and decrease of the wind velocity are seen in each regression function, and the tendency that Lwind become higher when frequency is lower are seen.

Table.2 Regression coefficients

System 1

frequency(Hz)	coefficient A	coefficient B	coefficient C
1	49.8	69.0	24.1
1.25	48.0	72.6	25.6
1.6	45.5	71.3	27.2
2	43.3	72.1	28.1
2.5	41.1	69.6	28.5
3.15	39.5	67.2	27.6
4	38.0	65.0	26.4
5	35.7	65.1	26.4
6.3	34.2	57.5	25.9
8	33.5	43.3	24.2
10	34.9	23.3	20.7
12.5	33.0	14.8	19.4
16	31.7	5.0	16.4
20	34.3	−9.0	11.6
25	33.2	−15.9	9.3
31.5	33.1	−21.0	6.5
40	31.4	−21.3	5.9
50	31.0	−15.9	4.5
63	28.6	−8.0	4.8
80	22.6	2.5	8.1

System 2

frequency(Hz)	coefficient A	coefficient B	coefficient C
1	39.7	57.4	22.5
1.25	38.6	58.6	22.7
1.6	37.1	57.4	23.0
2	36.5	56.9	22.0
2.5	35.7	54.8	21.6
3.15	35.1	53.4	21.1
4	34.5	46.2	20.9
5	32.2	48.2	21.8
6.3	31.7	37.9	21.2
8	32.1	24.7	19.3
10	34.7	4.6	15.3
12.5	32.8	1.7	14.2
16	31.6	−0.7	12.4
20	34.3	−10.6	9.2
25	32.3	−13.3	8.8
31.5	32.9	−19.8	6.8
40	29.9	−17.2	8.0
50	29.7	−14.9	6.6
63	27.4	−10.5	6.5
80	21.6	1.2	8.9

System 3

frequency(Hz)	coefficient A	coefficient B	coefficient C
1	38.0	56.4	19.9
1.25	36.8	53.0	20.6
1.6	34.5	56.2	21.5
2	33.9	51.4	20.6
2.5	32.7	46.4	20.6
3.15	32.4	40.2	19.3
4	32.6	29.6	17.8
5	31.0	28.7	17.6
6.3	31.3	17.9	15.9
8	32.5	7.8	13.6
10	35.3	−3.6	10.2
12.5	33.4	−4.4	10.2
16	32.0	−3.6	9.7
20	35.0	−15.0	7.3
25	32.7	−18.4	7.3
31.5	32.9	−23.2	5.2
40	30.6	−21.1	5.8
50	30.2	−16.6	4.6
63	27.9	−11.4	4.7
80	21.9	−1.5	7.1

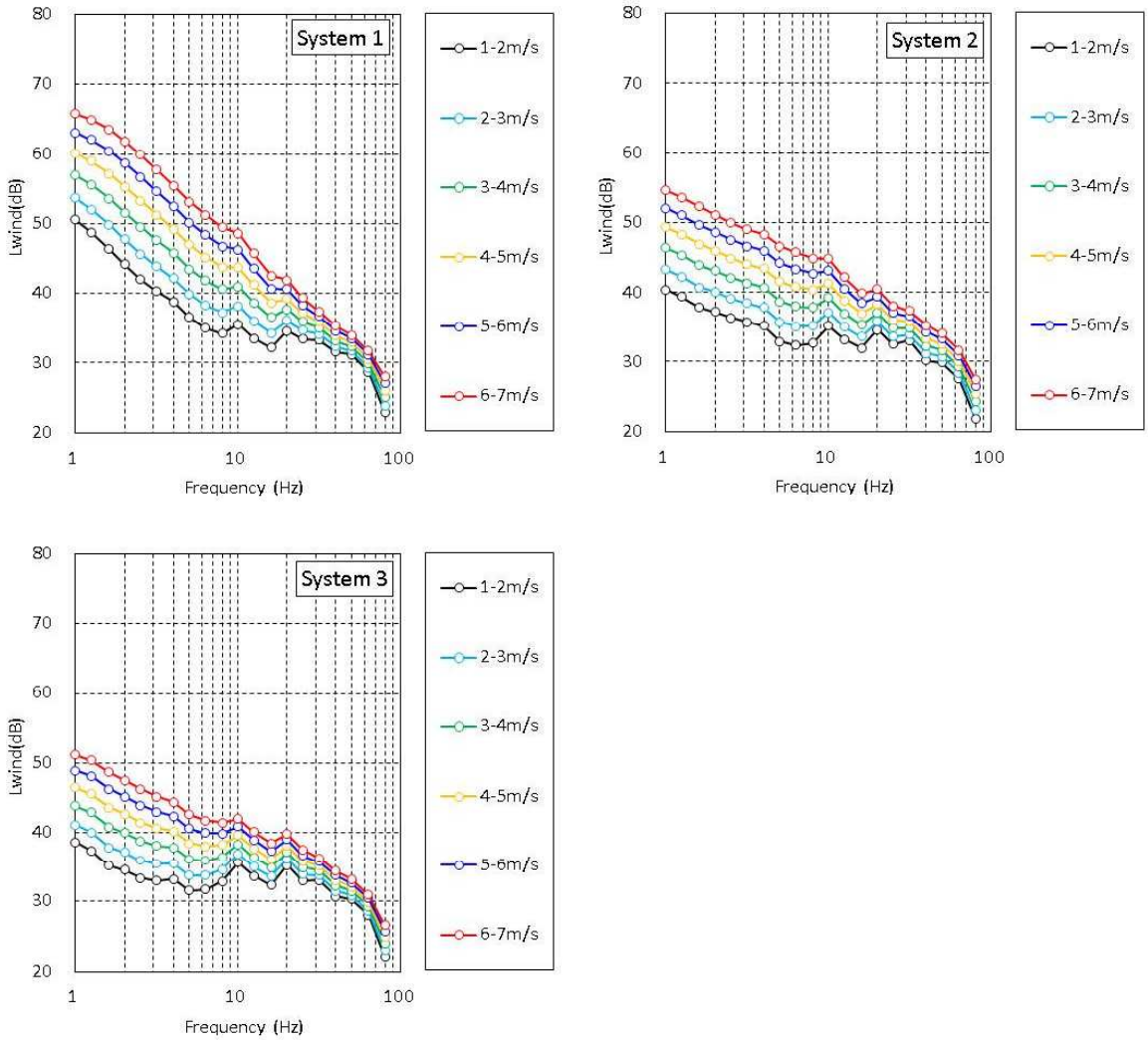


Fig.7 Frequency characteristics by regression functions (Iu=0.2)

4.4 Comparison of measured SPL and estimated Lwind Fig.8 shows time histories of measured SPL and estimated Lwind of 10 minutes. Fig.9 shows measured Leq and Estimated Leq for 10 minutes (1/3 oct. bamd). Time history of estimated Lwind is similar to measured SPL. This tendency is seen in 3 different systems. In addition, $Leq_{,10min}$. of estimated Lwind(1/3 oct. band) is similar to measured $Leq_{,10min.}$. Fig.10 shows relationship between estimated Lwind and measured SPL from 22:00 to the next morning 6:00from 22:00 for one second. As the result, the tendency that Lwind is small to 1.2dB is seen in 3 systems for measured SPL. Therefore we could confirm that the estimation of Lwind is possible for different systems.

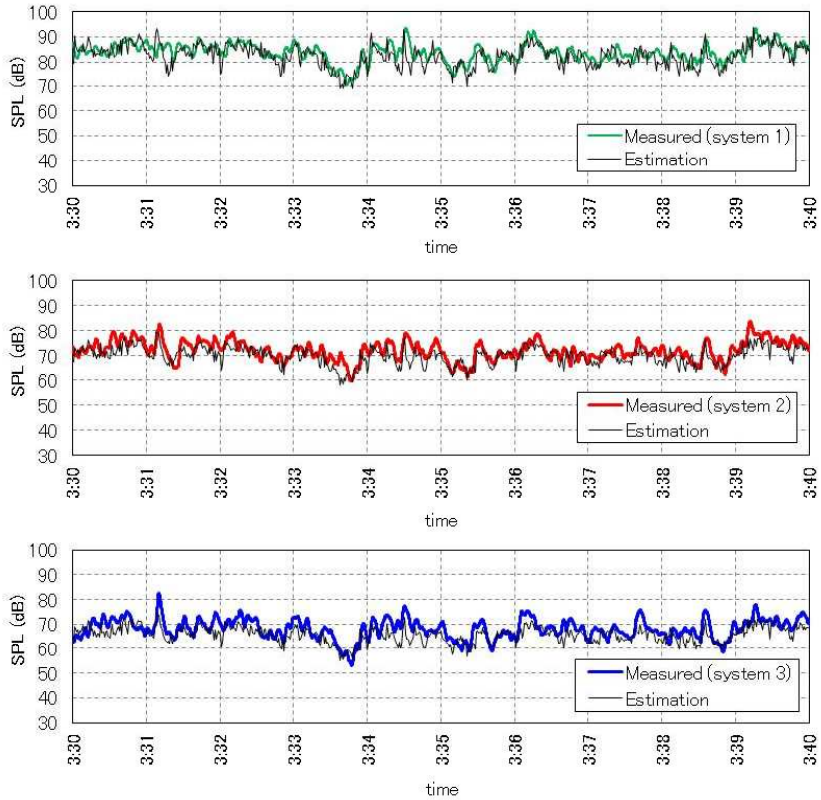


Fig.8 Time histories of measured SPL and estimated Lwind

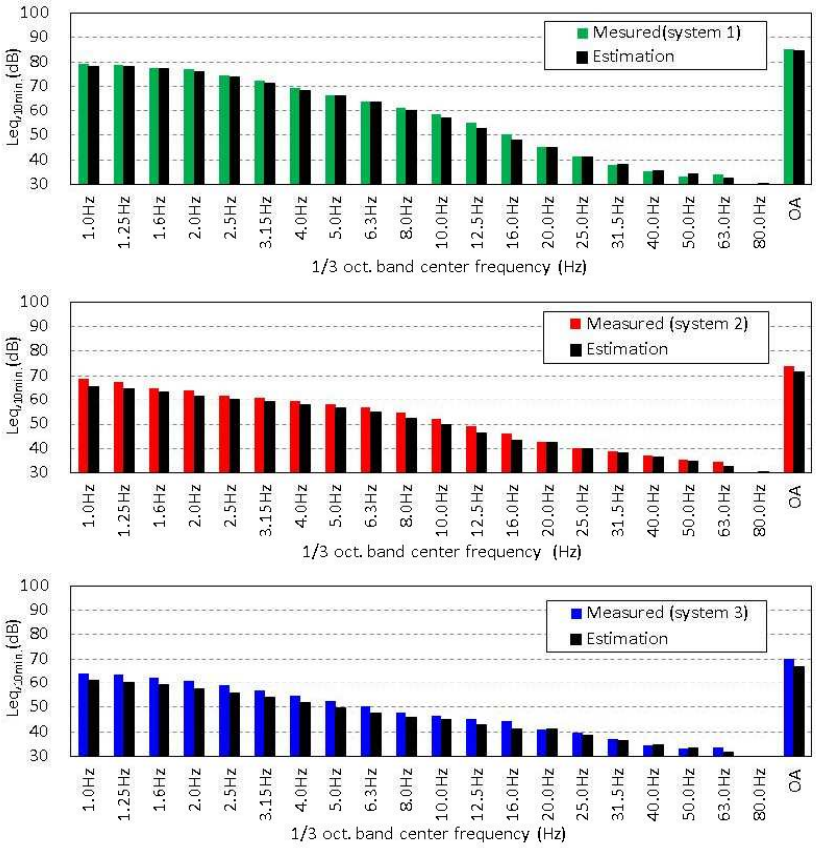


Fig.9 Measured Leq and Estimated Leq for 10 minutes (1/3 oct. bamd)

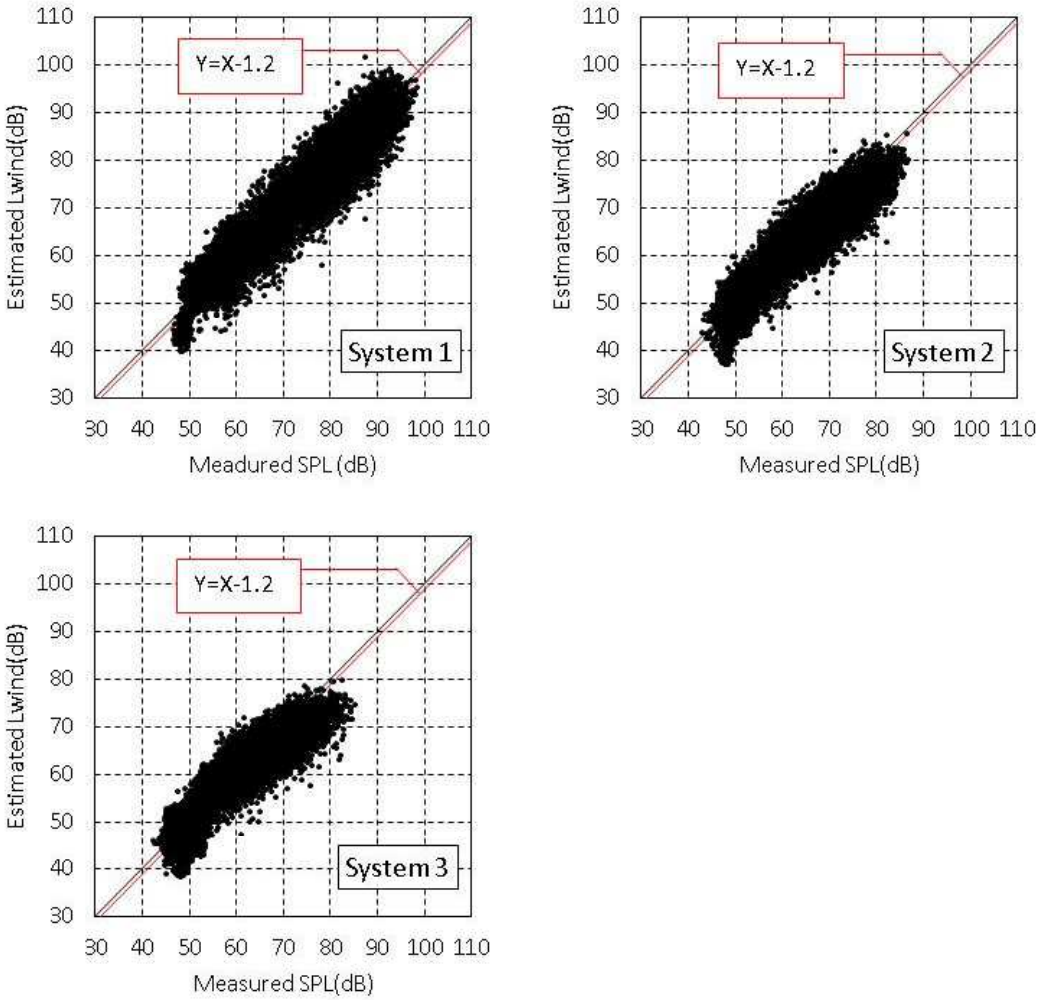


Fig.10 Relationship between estimated Lwind and measured SPL

5. Conclusions

We measured field data and tried the estimation of wind noise effect by new regression function in consideration of component of wind noise. As the result, new regression function is useful was confirmed. In addition, we confirmed that estimation of wind noise effect by different measurement system is possible.
We assume that this wind noise estimation is the example that is available for measurement of low frequency sound pressure in wind turbine.

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