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Measuring method of wind turbine noise at residential area – Consideration by using various noise indices–

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Abstract

Complaints against wind turbine noise are recently increasing in Japan. Then, exact measuring method of the wind turbine noise is needed to investigate the occurrence of the complaints.

According to the IEC 61400-11, calculating energy-averaged value for more than one minute of the wind turbine noise is recommended in the measurement. However, when we measure the wind turbine noise at area close to the residents, it is usually far from the wind turbine, and then the noise measurement is easily influenced by the background noise or the wind noise around the microphone fitted to the sound level meter. These conditions probably prevent to measure the wind turbine noise correctly by using the energy-averaging method for one or ten minutes.

Therefore, we have studied measuring and data processing methods of the wind turbine noise by using various noise indices such as L_{eq} and L_x, based on the field measurement at distances of 100, 200 and 400 m from a wind turbine located upward.

As a result, we have found that continuous measurement of L_{eq} calculated by averaging for any 10 seconds ($L_{eq,10s}$) is appropriate and allows us to effectively exclude the data contaminated by the wind noise, birds' cry, and pass-by noise of the vehicles that occurred suddenly.

1. Introduction

As one of the energy sources that can realize both preservation of global environment and national energy security, wind energy is rapidly being developed around the world. According to the global trend, introduction target of the wind power has been set to 300 million kW up to 2010 in Japan, and the wind power plants have been steadily constructed. Then, some of them are at around the residential areas.

As a result, complaints against wind turbine noise are recently increasing in Japan. Then, exact measuring method of the wind turbine noise is needed to investigate the causes of the complaints. According to the IEC 61400-11 [1], calculating energy-averaged value of the wind turbine noise for more than one minute is recommended in the measurement that the microphone is set directly on a hard plate and is covered by both a primary and a secondary windscreen.

However, when we measure the wind turbine noise at area close to the residents, where are usually far from the wind turbine, attenuation of the noise is getting larger with increasing distance and, therefore, the noise measurement is easily influenced by the background noise and/or the wind noise around the microphone fitted to the sound level meter. These conditions probably prevent to measure the wind turbine noise correctly by using the energy-averaging method for one or ten minutes described above.

The Ministry of the Environment, the Government of Japan (hereafter, MOE) has started investigation on the current situation of the noise generated from the wind turbines in detail. In the paper, we have studied measuring and data processing methods of the wind turbine noise by using various noise evaluation indices such as L_{eq} and L_x, based on the field measurement carried out by the MOE. From the literature survey [2, 3], we have found that various noise indices such as not only L_{eq} but also L_x are used to evaluate the wind turbine noise in the world.

2. Field measurement in a wind farm

2.1 Outline of measurement of wind turbine noise

Figure 1 is a ground plan of a wind farm where the field measurement has been performed, and six wind turbines were scattered about over a flat farming area. Among them, a wind turbine (no.3) was used to the measurement and was about 420 m or more distant from the others.

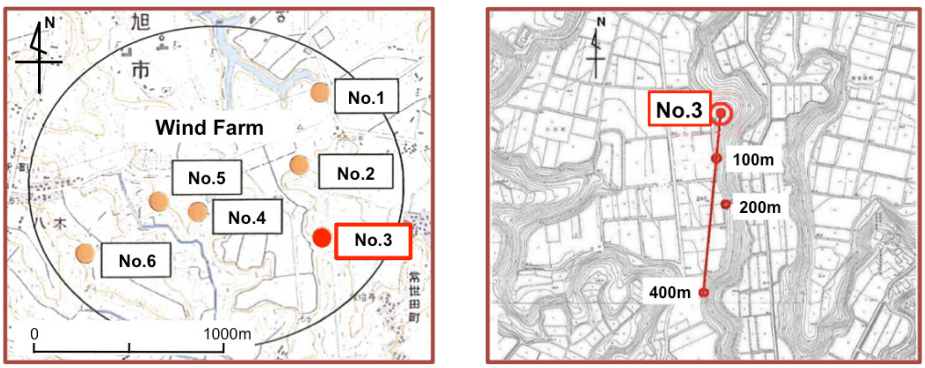


Figure 1 Ground plan of a wind farm for wind turbine noise measurement.

The wind blew from northeast direction on the day for the measurement, and the wind speed was 7.5 m/s in constant at the height of nacelle during the measurement. Therefore, the measuring points were set up at 100, 200 and 400 m away from the wind turbine downward, as shown in right-hand side of the Figure 1. Both a sound level meter (LA1250K, ONOSOKKI) and a low frequency sound level meter (NA18A, RION) were placed at each measuring point, and the output signals were recorded simultaneously on the data recorder. The sound level meter fitted with a 90-mm-diameter urethane spherical windscreen was on a tripod 1.2 m height from the ground. The low frequency sound level meter, which was fitted with the same windscreen as the sound level meter and was covered with a hemispherical double-layered net windscreen [4] as a secondary windscreen, was on a plywood plate put directly on the ground to prevent the wind noise on the measurement. The cross-section of the hemispherical double-layered net windscreen is shown in **Figure 2**, and the wind noise reduction by the hemispherical double-layered net windscreen relative to the 90-mm-diameter spherical windscreen at 1.2 m height above the ground is plotted in **Figure 3**. We observed the wind noise reduction of around 8 dB by the urethane spherical windscreen on the ground at frequencies from 2 to 25 Hz. The reduction by the double-layered net windscreen was generally larger, and the reduction values were from 10 to 20 dB at the same frequency range. Furthermore, decrease of the reduction performance at frequency range more than 20 Hz was caused by background noise.

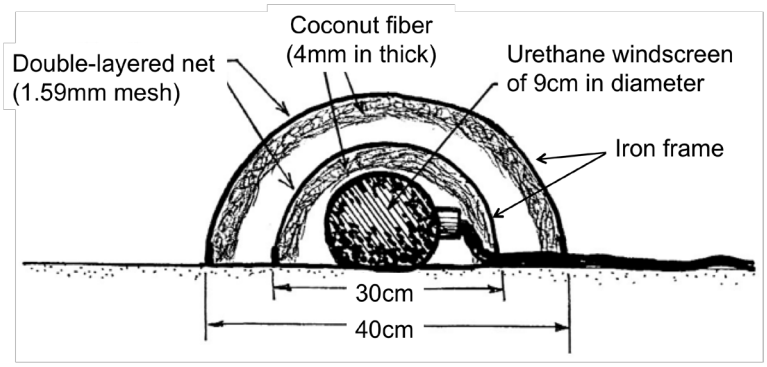


Figure 2 Cross section of hemispherical double-layered net windscreen.

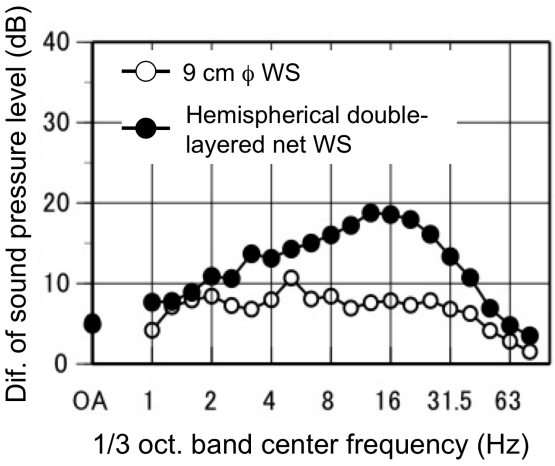


Figure 3 Relative noise reduction to a 90-mm-diameter urethane spherical windscreen at 1.2 m height above ground (wind speed: 5-8 m/s).

The wind turbine no.3 was forcibly stopped in operation only for 10 minutes for the background noise measurement, while the other turbines were continuously operating.

The outline of the wind turbine for the measurement is shown in **Table 1**. It was upwind type with the rated power of 1.5 MW and the total height was 100 m from the ground surface.

Table 1 Outline of the wind turbines

Total Height (m)	100	Cut-in Speed (m/s)	3
Rated Power (MW)	1.5	Cut-out Speed (m/s)	25
Rated Wind Speed (m/s)	12		

2.2 Data processing

We calculated equivalent continuous sound pressure levels averaged for any 10 s ($L_{eq,10s}$) of the wind turbine noise measured downward. In addition, following several measures were calculated from the same data.

- $L_{eq,10m}$ that was obtained from averaging instantaneous values of the sound pressure level every 0.1 s for 10 minutes.
- Mean of $L_{min.1m}(L_{eq,10s})$ that was obtained from averaging the minimum values of $L_{eq,10s}$ in each one minute.
- $L_{min.10m}(L_{eq,10s})$ that was the minimum value of $L_{eq,10s}$ in each 10 minutes.
- L_x that was percentile level and L_5, L_{10}, L_{50}, $L_{90,}$ and L_{95} were calculated.

By comparing these values, appropriate method for the data processing or evaluation of the wind turbine noise was examined.

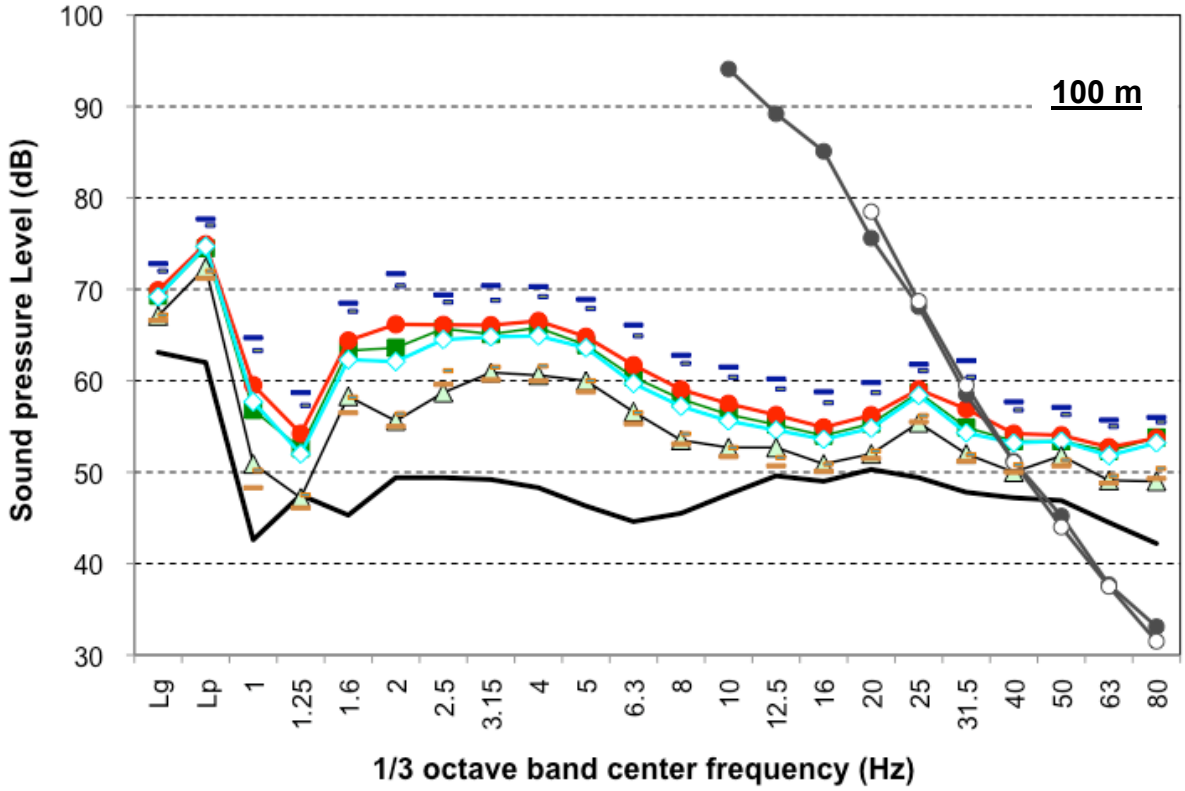
3. Results

3.1 Low frequency sound

Frequency analyses in low frequency range of the wind turbine noise measured at each point were performed, and the results were shown in **Figure 4**. Two hearing thresholds for low frequency sound [5, 6] were added for the comparisons. The sound pressure levels by the noise indices were below the two thresholds at frequencies less than 25 Hz.

(1) Influence of background noise and wind noise

Black-thick lines in Figure 4 indicate frequency spectrums of the background noise measured at each point when the wind turbine has been stopped. Since the sound pressure levels at all the frequencies of the background noise at 100 m were smaller than those of the wind turbine noise, we confirmed that the wind turbine noise could be detected at this point. However, the signal to noise ratios in frequency range from 10 to 80 Hz at both 200 and 400 m became insufficient because of attenuation of the



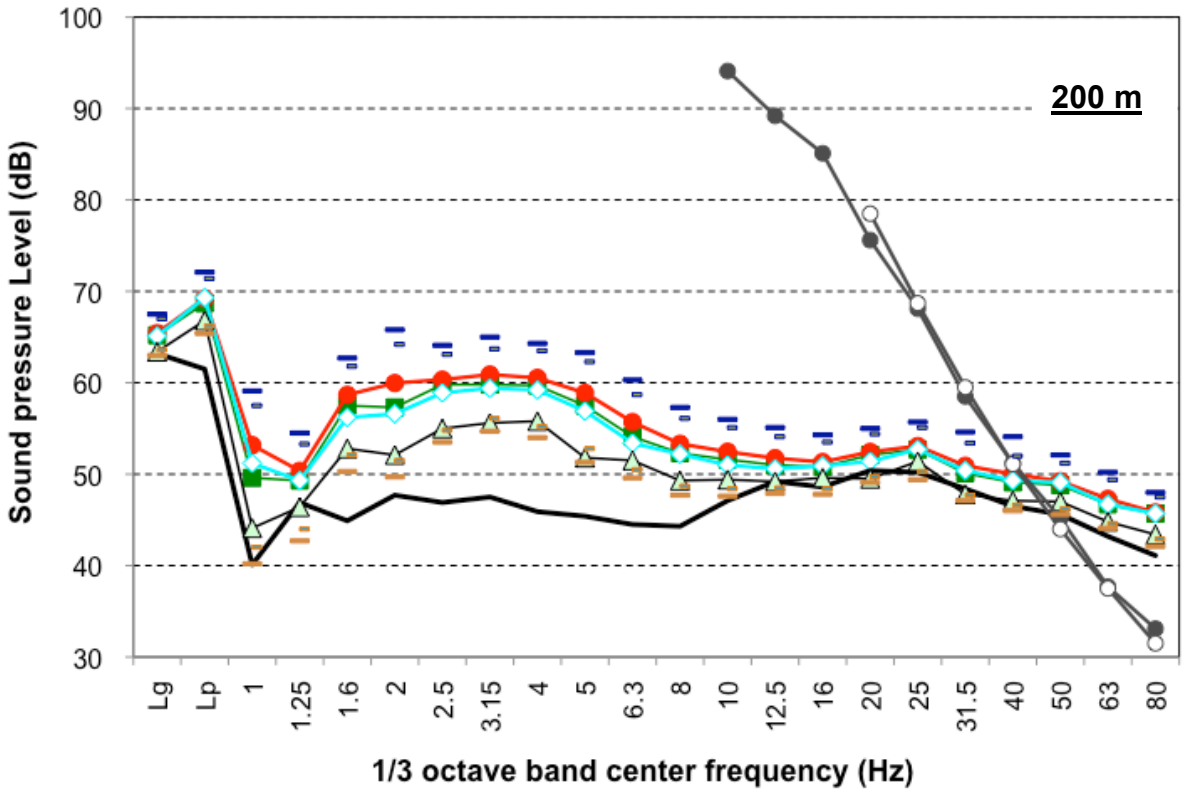


Figure 4 Low frequency spectrums of wind turbine noise evaluated by several noise indices at each measuring point (continued on next page).

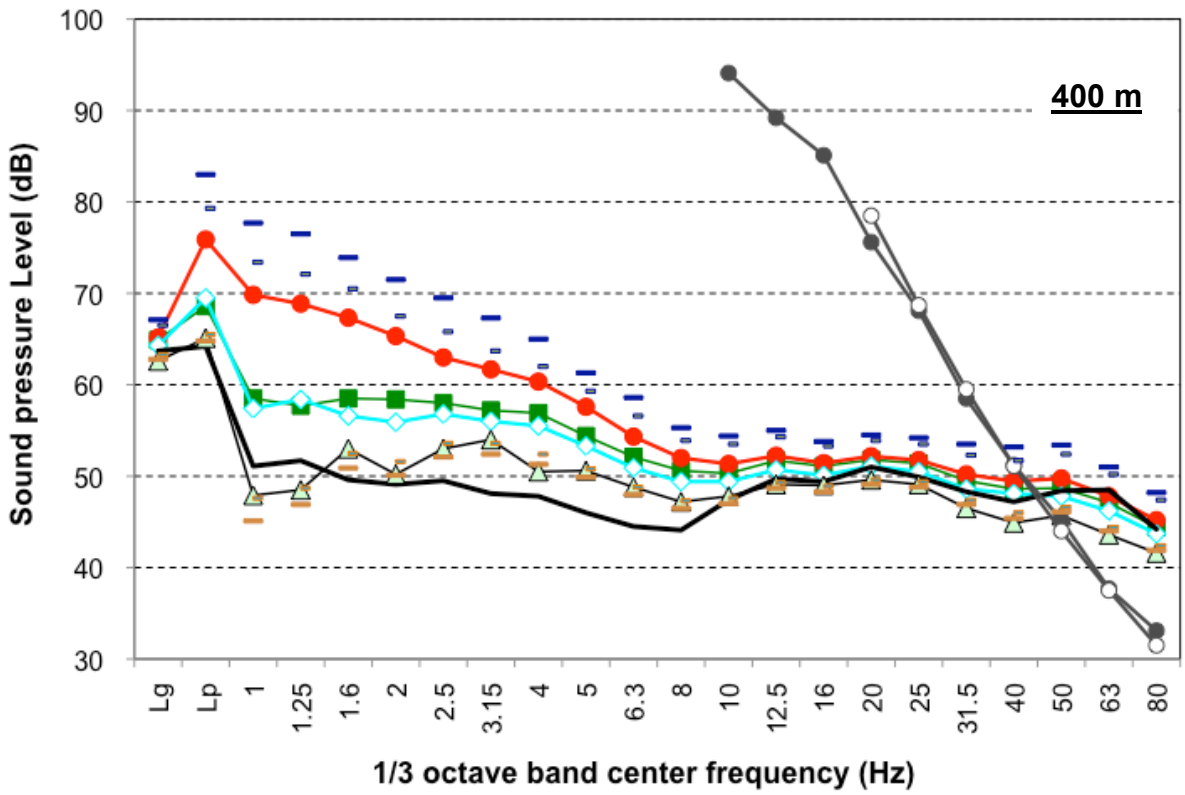


Figure 4 Low frequency spectrums of wind turbine noise evaluated by several noise indices at each measuring point. (Blue-long bar: L_5, Blue-short bar: L_{10}, Red-circle: $L_{eq,10m}$, Green-square: L_{50}, Orange-short bar: L_{90}, Orange-long bar:L_{95}, Diamond: Mean of $L_{min,1m}(L_{eq,10s})$, Triangle: $L_{min,10m}(L_{eq,10s})$, Black-thick: Background noise, Gray-circle: Threshold by Ref. [5], Gray-open-circle: Threshold by ISO 226).

wind turbine noise. In addition, the sound pressure levels of the background noise at frequencies of 1 to 8 Hz at 400 m were different from those observed at 100 and 200 m, and increased. This is probably because these frequencies were influenced by the wind noise generated at around the microphone. The noise indices such as L_5, L_{10}, and $L_{eq,10m}$ seem to be affected easily by the wind noise, since the levels of these indices clearly increased at the frequencies.

(2) Characteristics of wind turbine noise

As compared to the spectrum of the background noise at 100 m, the dominant frequency components of the wind turbine noise seemed to range from 1.6 to 6.3 Hz in 1/3 octave band, and the 25 Hz band was slightly tonal. Similar tendency was seen at the measurement of 200 m, although the tonal peak at 25 Hz was not clear.

(3) Comparisons between noise evaluation indices

- $L_{eq,10m}$

The sound pressure levels of $L_{eq,10m}$ at 100 and 200 m were almost the same as those of L_{50}. At 400 m, the levels of $L_{eq,10m}$ were almost the same as L_{50} at frequencies more than 10Hz. This is because the other frequencies seemed to be

influenced by the wind noise, and then the sound pressure levels became closer to those of L_{10}.

- Mean of $L_{min.1m}(L_{eq,10s})$

The sound pressure levels of mean of $L_{min.1m}(L_{eq,10s})$ were very close to L_{50} at all measuring points. The levels at frequencies less than 10 Hz were still stable, even when the increase in the levels of $L_{eq,10m}$ were observed by the effect of the wind noise. This may suggest that the mean of $L_{min.1m}(L_{eq,10s})$ is not influenced by the wind noise easily in the measurement of wind turbine noise.

- $L_{min.10m}(L_{eq,10s})$

The sound pressure levels of $L_{min.10m}(L_{eq,10s})$ were very close to L_{90} or L_{95} at all measuring points. While we may acquire the sound pressure levels of wind turbine noise stably by $L_{min.10m}(L_{eq,10s})$, this seems not to reflect changes of the wind turbine noise sufficiently and may result in underestimation of the low frequency components.

3.2 Audible sound

Frequency analyses in audible range of the wind turbine noise measured at each point were performed, and the results were shown in **Figure 5**. The marks in the figure are the same as those in figure 4. We could hear the wind turbine noise easily at the measuring points of 100 and 200 m, although we slightly heard the noise at 400 m.

(1) Influence of background noise

While the sound pressure levels at all the frequencies of the background noise at 100 m were smaller than those of the wind turbine noise, we found influence of the background noise at frequencies from 1 to 10 kHz at 200 m and from 3.15 to 4 kHz at 400 m. From re-analyzing the data of wind turbine noise recorded, we found that increase in the levels at 3.15 to 4 kHz was caused by birds' cry. The noise indices such as L_5, L_{10}, and $L_{eq,10m}$ seem to be affected easily by the background noise, since the levels of these indices clearly increased at the frequencies described above.

(2) Characteristics of wind turbine noise

Tonal components at 160 and 200 Hz were appeared at 100 and 200 m points, and these can be still observed at 400 m. Small peak at 25 Hz was also seen at 100 m.

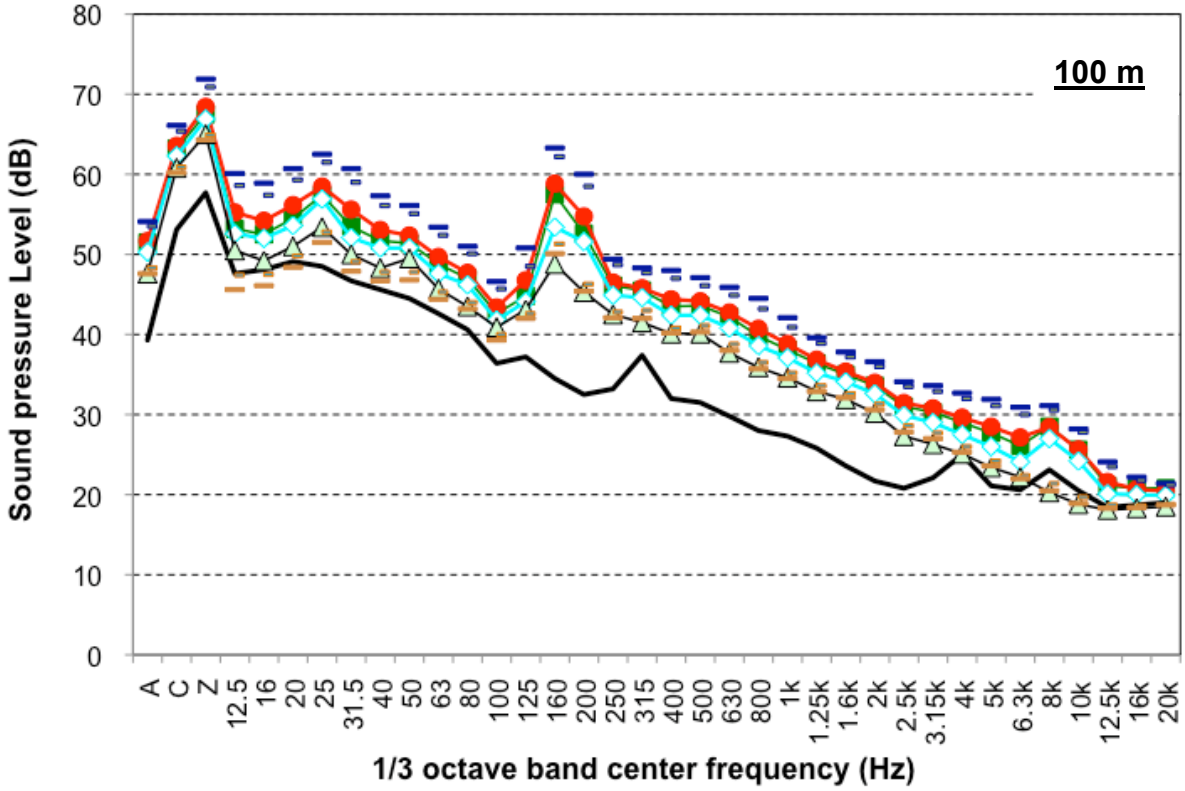
(3) Comparisons between noise evaluation indices

- $L_{eq,10m}$

The sound pressure levels of $L_{eq,10m}$ at 100 and 200 m were almost the same as those of L_{50}. However, the levels of $L_{eq,10m}$ at 200 and 400 m became larger at frequencies around 4 kHz. It is noted that $L_{eq,10m}$ is influenced by temporary noises such as birds' cry and so on.

- Mean of $L_{min.1m}(L_{eq,10s})$

The sound pressure levels of mean of $L_{min.1m}(L_{eq,10s})$ were very close to L_{50} at all



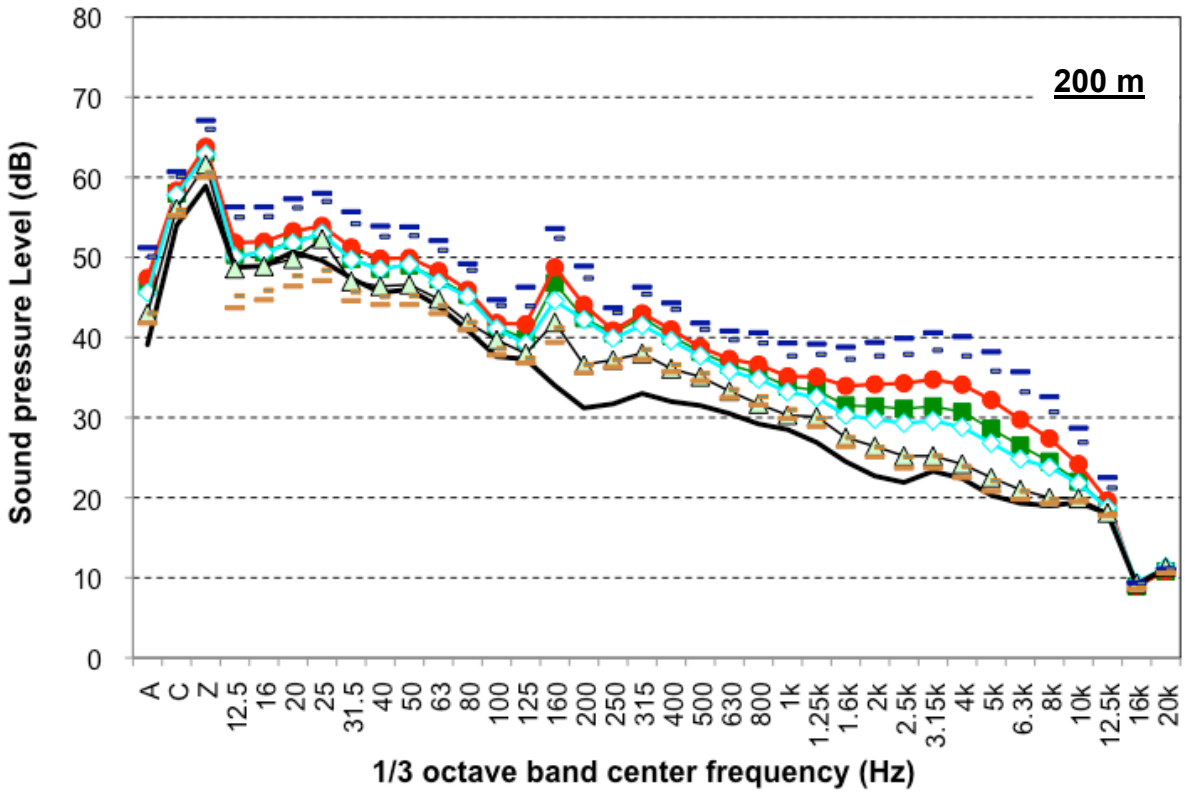


Figure 5 Audible frequency spectrums of wind turbine noise evaluated by several noise indices at each measuring point (continued on next page).

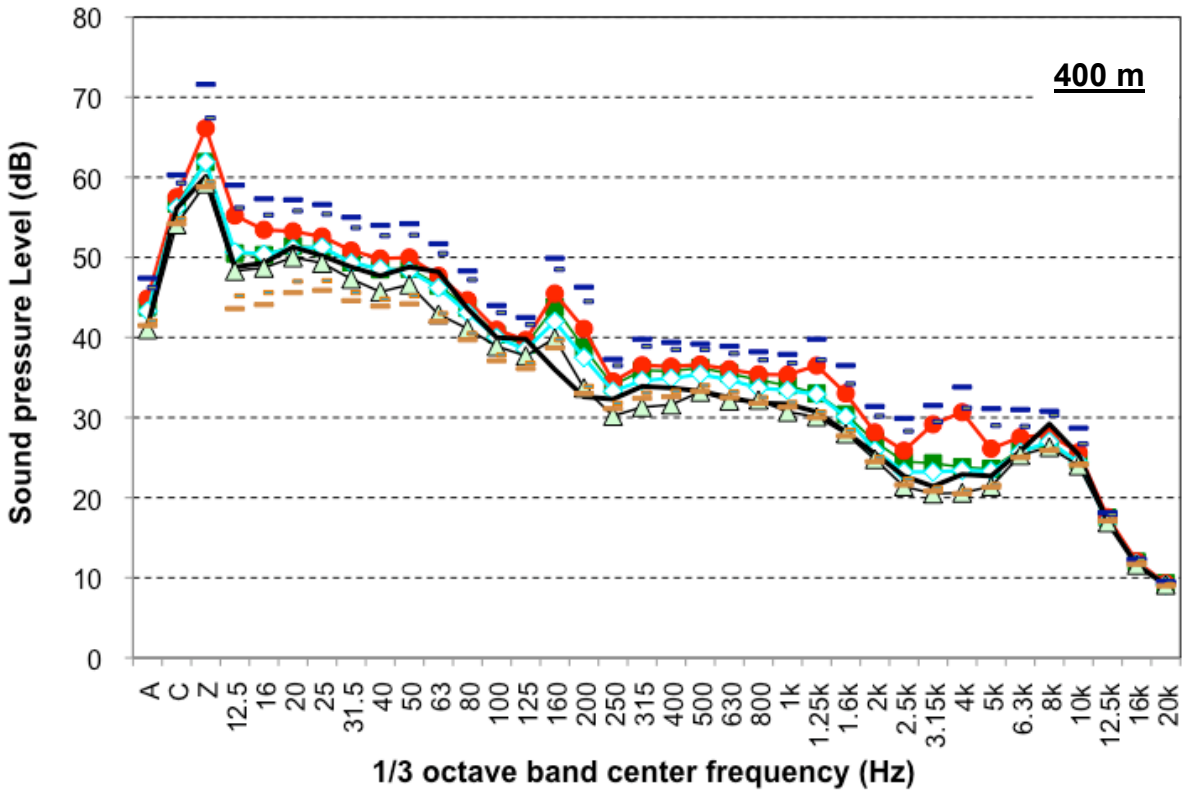


Figure 5 Audible frequency spectrums of wind turbine noise evaluated by several noise indices at each measuring point. (Blue-long bar: L_5, Blue-short bar: L_{10}, Red-circle: $L_{eq,10m}$, Green-square: L_{50}, Orange-short bar: L_{90}, Orange-long bar:L_{95}, Diamond: Mean of $L_{min,1m}(L_{eq,10s})$, Triangle: $L_{min,10m}(L_{eq,10s})$, Black-thick: Background noise).

measuring points. The mean of $L_{min.1m}(L_{eq,10s})$ were still stable at frequencies around 4 kHz, and therefore this may suggest that the mean of $L_{min.1m}(L_{eq,10s})$ is not influenced by the background noise in the measurement.

- $L_{min.10m}(L_{eq,10s})$

The sound pressure levels of $L_{min.10m}(L_{eq,10s})$ were very close to L_{90} or L_{95} at all measuring points. While we may acquire the sound pressure levels of wind turbine noise stably, $L_{min.10m}(L_{eq,10s})$ seems not to reflect changes of the wind turbine noise, and may result in underestimation of the wind turbine noise.

5. Conclusions

Field measurement of wind turbine noise has been performed, and appropriate method for the data processing or evaluation of the wind turbine noise was examined by comparing with the values of several noise indices.

Since any noise indices could not exclude the influence of wind noise or temporary noises completely, either of the following operations is essential to analyze the wind turbine noise exactly.

- The data without any these influence were selected from whole measurement and analyzed.
- First, $L_{eq,10s}$ is continuously calculated under the condition where the time was exactly synchronized among all the measuring points, and secondly the data uncorrelated in time with others were excluded and then analyzed.

The wind noise and temporary noises have occurred independently on the measuring points and/or the measuring periods. Therefore, it is effective basically to make data processing by short time-interval such as 10 s to exclude any these influences well. Furthermore, the data processing by using the longer time-interval such as one minute can be applied only when the wind noise or temporary noises are not influenced the measurement. Anyhow, it is still necessary to continue the measurement and accumulate effective data set of the wind turbine noise, in order to establish the appropriate data processing or evaluation.

Acknowledgement

The Institute of Noise Control Engineering, Japan (INCE/J) was commissioned to make an investigation on low frequency noise such as moving sources etc. by MOE in 2009. This paper is an arrangement in some parts of the investigation report.

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