

TECHNICAL REPORT

Acoustic performances of a vertical board for wind turbine noise immission measurements

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Abstract: In many measurement situations of wind turbine noise immission, the effects of background noise and reflected sound waves from building facades on the measurements are a major problem in addition to the wind-induced noise on the microphone, resulting in a low signal-to-noise ratio of measurements. The use of a vertical board mounted with a microphone was suggested in the document of IEA recommended practices in case of such a problem. Acoustic tests of the board had been carried out on two types of ground to investigate whether performances of the board outdoors are as expected. Results of the tests revealed that one-third octave band measurements were affected by the diffraction of sound waves incident on the board and agreed well with the previous results for a lower to mid frequency range, while the measurements were found to have irregularities as large as ± 2 dB for higher frequencies. The A-weighted measurements were found to be within $+6$ dB ± 0.5 dB compared to that of the free-standing microphone. The shielding effect of the board turned out to depend both on the angle of incidence to the board and microphone position and was found to be as large as 10 dBA.

Keywords: Wind turbine, Noise immission, Noise measurement, Vertical board, Background noise, Reflected sound

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1. INTRODUCTION

The document of IEA Recommended Practices for wind turbine noise immission measurements [1,2] describes measurement techniques and methods which enable characterization of the noise immission from wind turbines at a receptor location. For measurements, the document recommends the use of a free-standing microphone at a height of 1.2 to 1.5 m or 5.0 m. If it is necessary to suppress background noise or noise reflected from an adjacent surface such as a building facade or to suppress wind-induced noise on a microphone, it suggests the use of a large vertical board with a microphone at the designated position with its diaphragm flushed with the board surface. When this board is used, the guideline requires the subtraction of 6 dB from the measured A-weighted output level due to the pressure doubling on the board surface. The board could be useful since the sound level from a wind turbine is of the same order of magnitude as the background noise level in many measurement situations.

Details concerning acoustic measurements by a vertical board in the document [2] are based on research by Fegeant

[3,4] who studied the effects of scattering of a sound wave incident on the board theoretically and experimentally and found the optimal microphone position to shield the background noise or reflected sound from, e.g., the building surface. However, the work by Fegeant treated the problem in a free field and thus neglected the ground which reflects a sound wave from the source to the board and reflects diffracted waves from the board.

While this novel technique appears interesting, the effects of the ground on measurements were left unknown. Furthermore, it is yet to be confirmed if A-weighted measurements obtained using the board give exactly $+6$ dB compared to the free-standing microphone output and how much of a shielding effect could be expected from the board for the actual noise measurements. Outdoor tests were expected to be suitable from this viewpoint, and thus experiments were carried out to evaluate acoustic performances of a vertical board on two types of flat ground. This report describes the experimental methods and results with discussion.

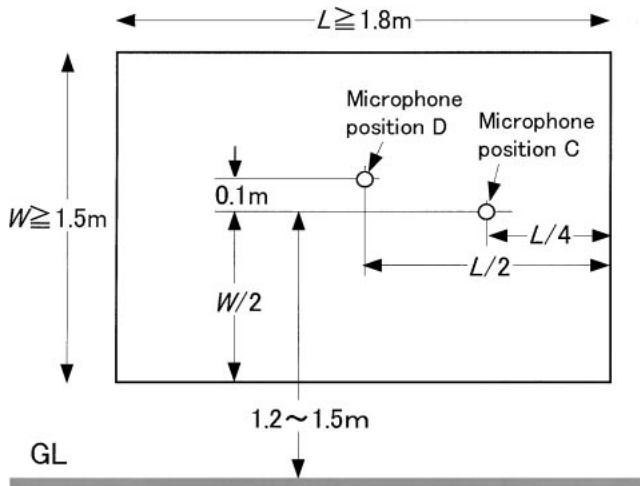


Fig. 1 Board size and microphone positions provided by IEA recommended practices [2].

2. TEST METHODS

2.1. Vertical Board

The vertical board recommended by the guideline [2] is rectangular with minimum dimensions of 1.5 m × 1.8 m and is made of acoustically hard materials, e.g., a piece of plywood or hard chip-board with a thickness of at least 12 mm. The recommended microphone position on the board is either position C or D as depicted in Fig. 1. Position C is expected to be optimal for avoiding the effects of scattering from the edges on the measurements and is recommended when the board is used to reduce the influence from background noise sources or reflected sound waves behind the board. Position D is recommended when the board is used to reduce wind-induced microphone noise.

The board tested outdoors was made of 16-mm-thick plywood with dimensions of 1.5 m × 1.8 m. Fifteen microphones were mounted on the x - y axes with equal spacing of 20 cm on the board surface (see Fig. 2) so that their diaphragms were flushed with the board surface. The microphones mounted on the board are called board microphones M_i ($i = 1$ to 15) hereafter. The position marked by “x” in the figure corresponds to position C referred to in Fig. 1. Note that position C ($x_C = 45$ cm) is located between M_7 ($x_{M7} = 40$ cm) and M_8 ($x_{M8} = 60$ cm) and is closest to the position of M_7 .

2.2. Test Methods

A loudspeaker was placed 1.5 m above the ground and was driven by the white noise signal. A free-standing microphone m_2 (called stand microphone hereafter) or the center of the vertical board was positioned 21.9 m from the speaker and at 1.2 m above the ground. The stand microphone m_1 positioned 1.15 m from the speaker and 1.5 m above the ground was used to confirm the output

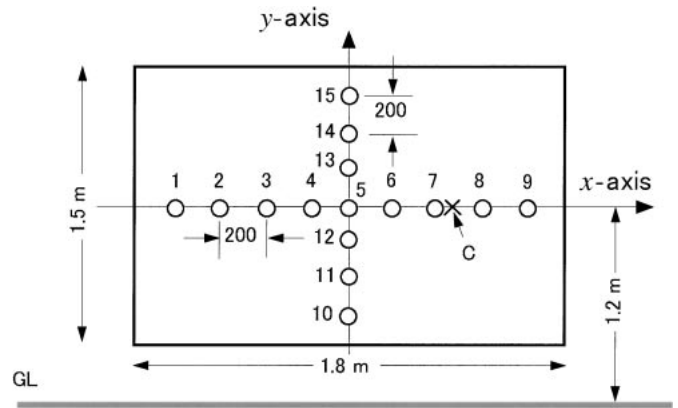


Fig. 2 Board size and microphone positions (denoted by a circle and numbers) on the test board viewed from a speaker. Fifteen microphones were flush mounted on the board surface.

level of the speaker. This arrangement sets the reflection position of the sound wave incident to the center of the board around 10 m in front of the board. For a wind turbine whose rotor center is at a 40 m height from the ground surface, which corresponds roughly to a 600 kW class turbine, the position where the sound wave from the source is reflected from the ground and is incident on the board is estimated to be around 9 m from the board at a typical measurement distance of 300 m from the turbine on the flat ground. This suggests that the sound waves incident on the board directly from the source and reflected from the ground could have the same degree of correlation with the current setup as far as the interference on the board surface is concerned.

The board was rotated around the y -axis to investigate possible effects of the angle of incidence on the measurements and the board angle θ is defined as shown in Fig. 3. The tests were carried out for the board angles of 0 degree and 30 degrees at site A, and 0 degree, 135 degrees and 180 degrees at site B (see next section for sites A and B). The surface facing the speaker is referred to as front surface and the opposite surface as back surface, hereafter. The situation for $\theta = 180$ degrees where the back surface is oriented normal to the speaker, is referred to as normal backward incidence, hereafter.

All microphones used for the tests were 13-mm-diameter free-field type with the same specifications. Since



Fig. 3 Plan view of the setup to describe the board angle.

the microphone outputs were free-field corrected against the diffraction of sound waves around a microphone, however this is not necessary for the board microphone, output levels of the board microphone were corrected to be harmonized with the response of the stand microphone for frequencies higher than 1 kHz based on technical data of the microphone.

Measurements were carried out carefully to avoid intruding intermittent background noise. Experiments were conducted on days with very low or no wind conditions.

2.3. Test Sites

The experiments were conducted at two selected sites (called site A and site B hereafter) in AIST Tsukuba Northern Office located in a quiet rural area surrounded mainly by farmland or woods and partly by private residences. Site A was a 200 m by 130 m flat space whose surface was covered by a 31-cm-thick structure composed of asphalt and concrete. This site can be regarded practically as a half free field with a hard reflecting boundary. Site B was a nearly flat space with a slight undulation covered by cut sod. There were no sound-reflecting structures or obstacles influencing the measurements at both sites.

3. RESULTS AND DISCUSSION

3.1. One-third Octave Band Response

3.1.1. Microphone responses

Figures 4(a) and 4(b) show one-third octave band responses for m1, m2 and M5 microphones with background noise of M5 at sites A and B, respectively. The one-third octave band and A-weighted sound pressure levels were obtained through a one minute RMS average for all microphone outputs. These graphs demonstrate that a sufficient signal-to-noise ratio was achieved for frequencies higher than 80 Hz. In the frequency responses of m2 and M5 microphones, clear dips located in the frequency range of 1 kHz to 1.25 kHz for site A and 400 Hz to 500 Hz for site B are observed. These dips are believed to have been created due to the interference of two sound waves incident on the board directly from the speaker and reflected from the ground and incident on the board. It is noted that the level of the response of M5 microphone is larger than that of m2 microphone for a full-frequency span for both sites and the difference of the two responses varies sensitively with the frequency particularly around the dip frequencies. This difference, defined as a relative response in the next section, is believed to be created due to the pressure doubling on the board surface and diffraction of the sound waves incident on the board.

3.1.2. Relative response

The relative response of $L(Mi)-L(m2)$ was determined for all board microphones, where $L(Mi)$ is the level of the

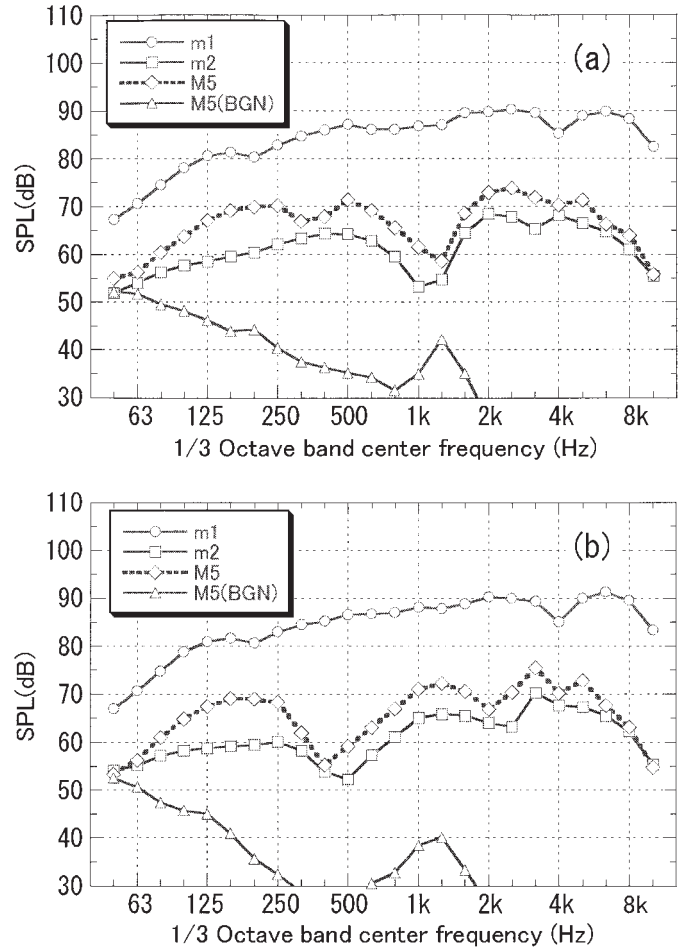


Fig. 4 Responses of the m1, m2 and M5 microphones to the speaker source and typical background noise at site A (a) and site B (b). The speaker was driven by a white noise signal.

board microphone Mi and $L(m2)$ is the level of the stand microphone. Figures 5(a) and 5(b) show the relative responses along the x and y axes, respectively, measured at site A for the board angle of 0 degree. It is noted that these responses show a tendency to fluctuate around +6 dB. Specific features of the fluctuation along the x axis are as follows; for the frequency range from 80 Hz to 250 Hz, the responses of two microphones located symmetrically with respect to the origin of the x - y coordinates are almost at the same level and the closer the microphone to the board edge, the smaller the response level; for the frequency range of 630 Hz to 3.15 kHz, the response level of the microphones are close to each other except for M1; for the frequencies higher than 4 kHz, the response levels for each microphone are scattered with irregularities as large as around ± 3 dB. For the responses along the y -axis, a similar feature to that observed in Fig. 5(a) is seen for the frequency range of 80 Hz to 250 Hz, while larger irregularities are observed for all microphones depending on their positions for the frequency range of 500 Hz to 3.15 kHz particularly around the dip frequencies as observed in Fig.

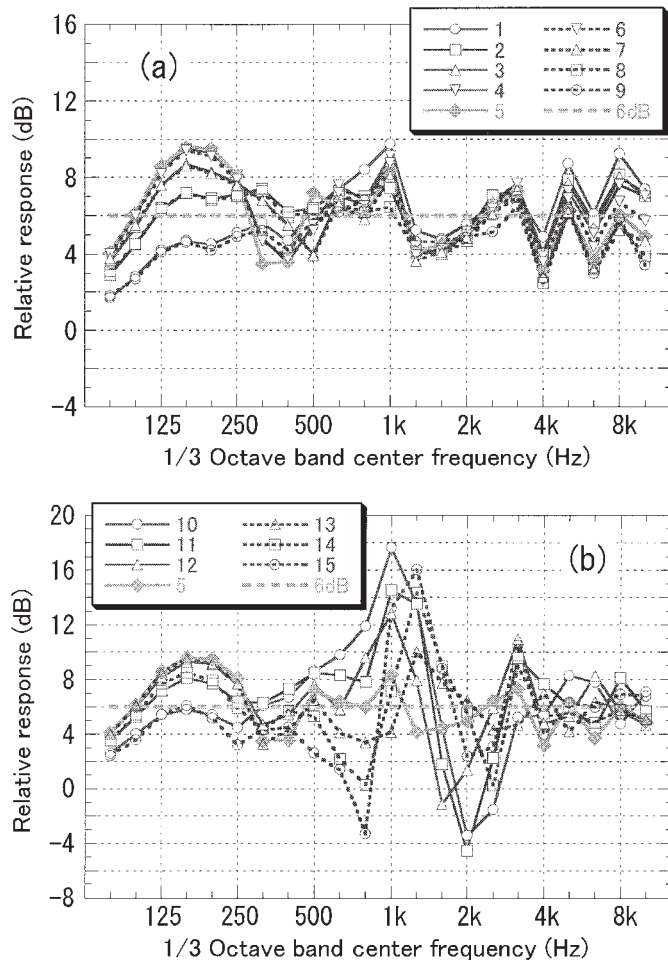


Fig. 5 Relative responses of fifteen microphones numbered 1 to 15 on the *x*-axis (a) and *y*-axis (b) measured at site A with the board angle of 0 degree.

4(a).

It is pointed out that the responses of M5 (center of the board) and M3 (M3 position is closest to position C as shown in Fig. 2) for the frequency range of 80 Hz to 800 Hz nearly coincide with the analytical and experimental results given by Fegeant [4] for corresponding microphone positions (center of the board and position C) and a frequency range of 160 Hz to 2 kHz. (The board dimensions of Fegeant were half of those presented here and thus a comparison was made by following the scaling law.) The discrepancy between Fig. 5(a) and the results by Fegeant appeared at frequencies higher than the dip frequency of 1 kHz. This suggests that the sound waves reflected from the ground and incident on the board are responsible for the irregularity in the frequency range from 1 kHz to 3.15 kHz. Irregularities which appeared at frequencies higher than 4 kHz were not reported by Fegeant, but the cause of these irregularities is unknown.

Figure 6 shows the responses for the board angle of 30 degrees at site A. Note that the specific feature of the

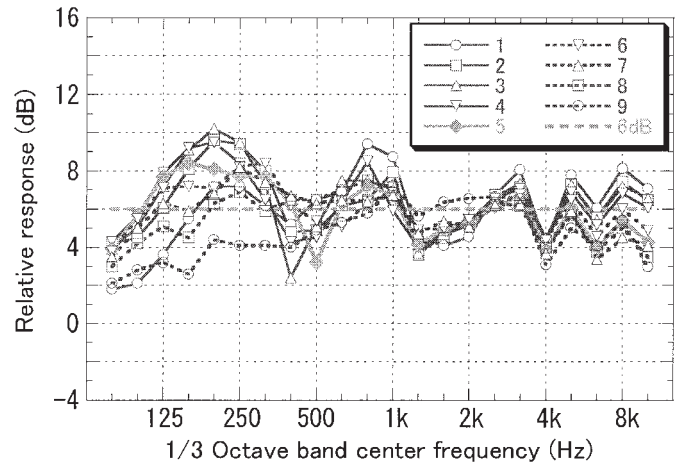


Fig. 6 Relative responses measured at site A with the board angle of 30 degrees.

response between two microphones positioned symmetrically as observed in Fig. 5(a) for the frequency range of 80 Hz to 250 Hz disappeared while the responses for higher frequencies show a similar feature to that in Fig. 5(a) except for the response of M9.

Figures 7(a) and 7(b) show the responses along the *x* and *y* axes, respectively, measured at site B for the board angle of 0 degree. It is noted that the responses in the frequency range of 80 Hz to 250 Hz are highly similar to those observed in Fig. 5(a). For frequencies higher than 500 Hz, the differences of the responses are relatively small and the same level of irregularity as that in Fig. 5(a) is observed for a frequency range of 2 kHz to 6.3 kHz. It should be noted that the levels of all responses for frequencies higher than 8 kHz became smaller than the responses observed at site A. Also, larger irregularities are observed along the *y*-axis in the dip frequency range in Fig. 7(b).

3.1.3. Shielding effects

Figures 8(a) and 8(b) give the relative responses along the *x*-axis measured at site B for the board angles of 135 degrees and 180 degrees, respectively. The shielding effect of the board is defined here by the difference of the levels of the board and stand microphones, and is equivalent to the relative response with an opposite sign. Large irregularities are particularly observed in the M5 response for the normal backward incidence as seen in Fig. 8(b), while the other responses show general tendencies that the shielding effect increases as frequency increases. It is noted that the response at the center of the board (M5), for example, is smaller than 0 dB for the frequencies lower than 315 Hz.

For the board angle of 135 degrees (see Fig. 8(a)), the shielding effect for the microphones located close to the edge (such as M1, M2 and M9) are rather small compared to that at the center of the board (M5). It is noted here that, as far as the spectral measurements are concerned, the

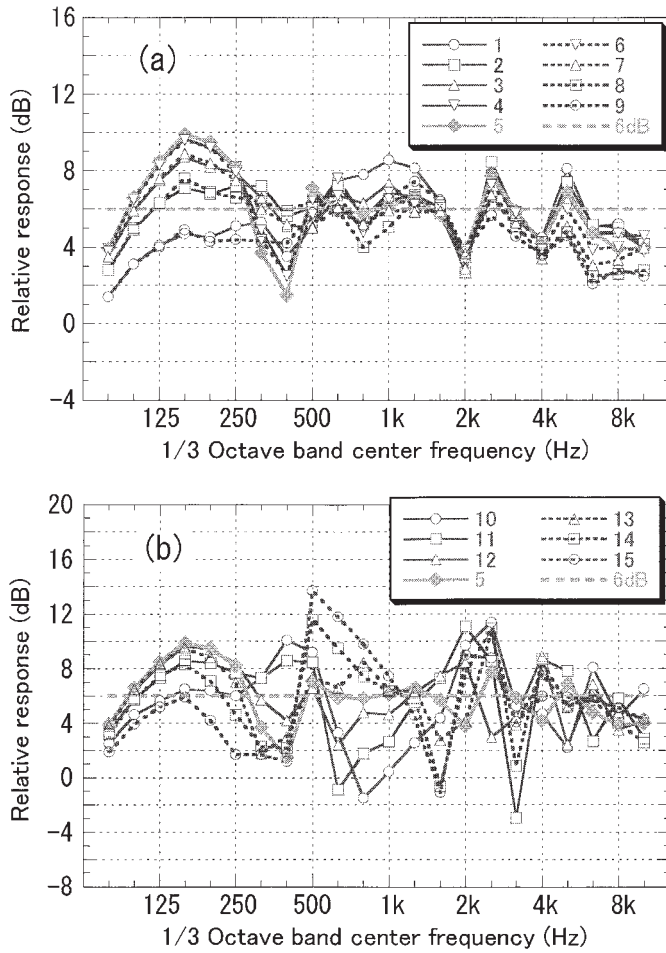


Fig. 7 Relative responses on the x -axis (a) and y -axis (b) measured at site B with the board angle of 0 degree.

shielding effect of the board depends both on the board angle and microphone position and thus a specific microphone position is not necessarily optimal for shielding a sound from sources behind the board.

3.2. A-weighted Response

The A-weighted response of the board microphone was tested using the frequency spectra given in Fig. 9. Note that the response of m1 microphone is band limited for frequencies higher than 2 kHz compared to the response shown in Fig. 4. This frequency band was set by referring to a measured spectral pattern for a large wind turbine.

Figures 10(a) and 10(b) show the A-weighted relative responses measured at site A for the board angles of 0 degree and 30 degrees, respectively. It is noted that the responses are smoothed compared to the one-third octave band measurements with irregularities and converged to the level of +6 dB within ± 0.5 dB for the x -axis responses of both given board angles. This smoothing effect compared to the one-third octave band measurements must have occurred simply due to the averaging effect by the energy sum of the components in the frequency range.

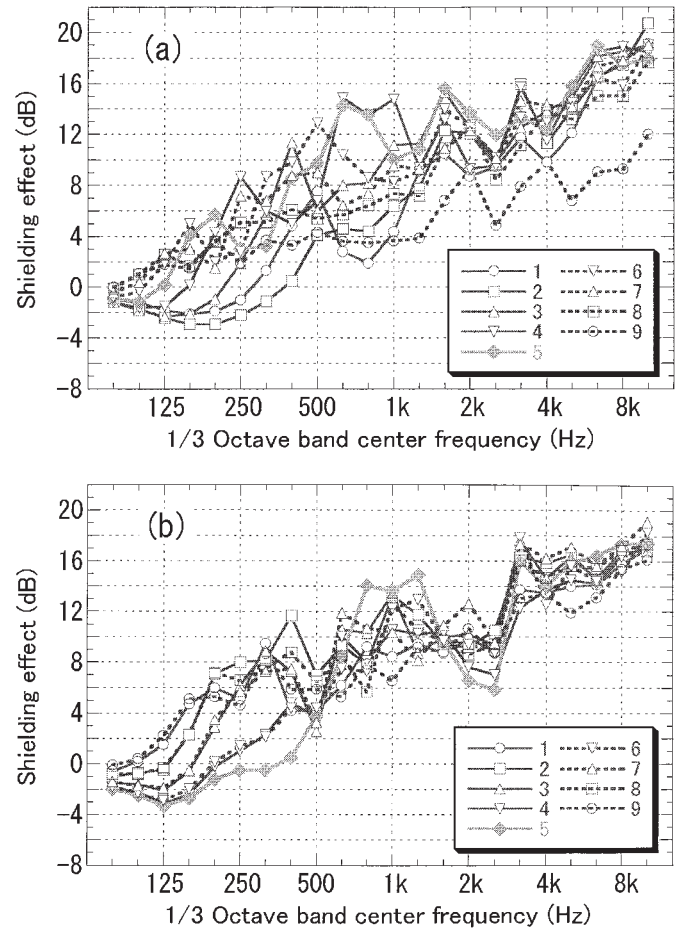


Fig. 8 Shielding effects of the board at site B for board angles of 135 degrees and 180 degrees.

Figures 11(a)–11(c) show the A-weighted responses measured at site B for the board angles of 0 degree, 135 degrees and 180 degrees, respectively. For the board angle of 0 degree, the levels along the x -axis are also found to converge to the level of +6 dB within ± 0.5 dB. It is noted that the shielding effects of around 10 dB were achieved for the normal backward incidence for a wide region along the x -axis as observed in Fig. 11(c). However, it is also noted that the shielding effect is reduced to around 8 dB for the board angle of 135 degrees except at the positions of $x = 60$ cm and $x = 80$ cm (each corresponds to the positions of M8 and M9, respectively) where the shielding effect is reduced to around 4 to 5 dB. The position of M9 being closest to the speaker for this board angle is noted.

The results obtained here are of course specific to the spectrum given in Fig. 9 and could be different for a different spectral pattern of a sound wave incident on the board microphone. However, since the irregularities observed in the spectrum scatter around +6 dB and a smoothing effect due to the energy sum of the components in the frequency range is expected, deviation of the measurements from +6 dB is also believed to be small for a different spectral pattern.

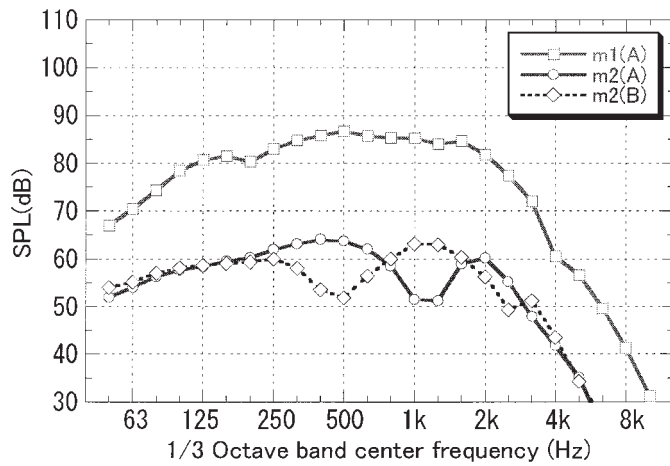


Fig. 9 Spectra of m1 and m2 microphone outputs used to determine the A-weighted response. Capitals A and B in the legend represent measurements at sites A and B, respectively.

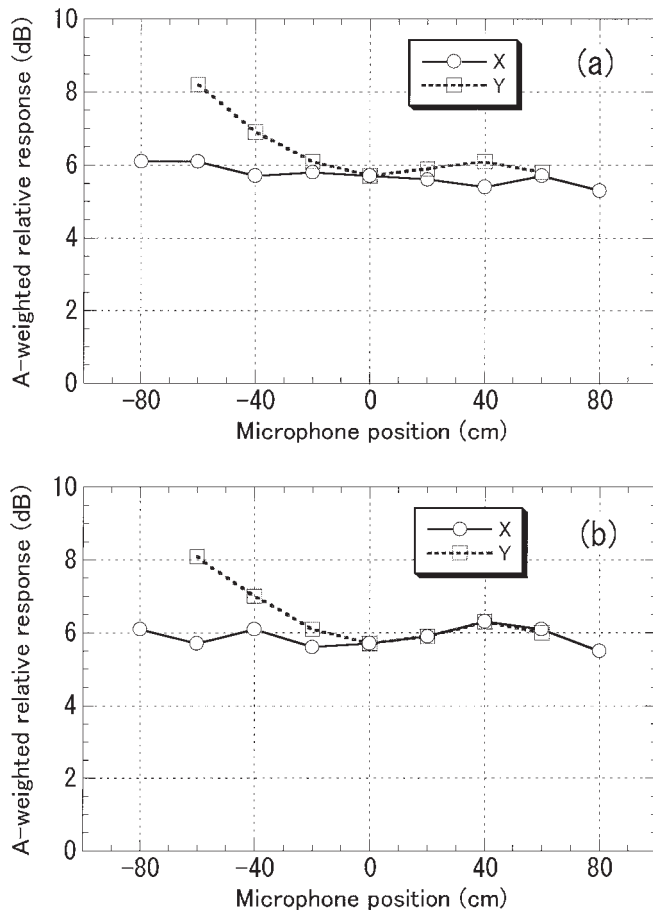


Fig. 10 A-weighted relative responses of the board microphones measured at site A for board angles of 0 degree (a) and 30 degrees (b).

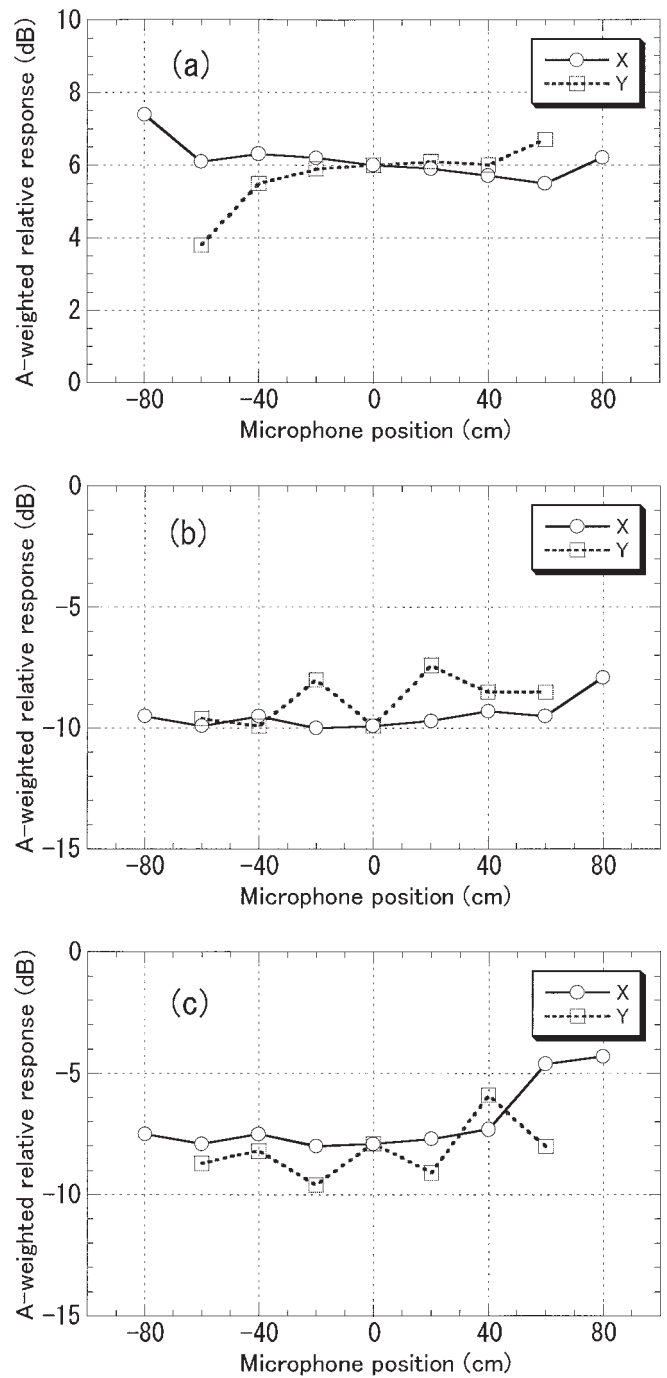


Fig. 11 A-weighted responses of board microphones measured at site B for board angles of 0 degree (a), 135 degrees (b) and 180 degrees (c).

4. CONCLUSIONS

Acoustic performances of a vertical board suggested for use in the document of IEA Recommended Practices [2] had been tested on two different types of ground using a setup simulating noise immission measurements for wind turbines. The following results were obtained from the tests:

- 1) The one-third octave band measurements of the board microphone were affected by the diffraction of sound waves incident on the board and agreed well with the free-field results [4] obtained analytically and experimentally for the lower to mid frequency range.
- 2) The one-third octave band measurements of the board microphone were found to have irregularities as large as around ± 2 dB for high frequencies compared to the measurements of the free-standing microphone, which were not mentioned in the previous work by Fegeant [4].
- 3) The A-weighted measurements of the board microphone were found to be within $+6$ dB ± 0.5 dB compared to that of the free-standing microphone for a wide range of the x -axis regardless of the type of ground and board angle.
- 4) The shielding effect of the board was found to depend both on the board angle and microphone position and the effect to the A-weighted response was found as large as 10 dBA.

ACKNOWLEDGEMENTS

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