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GROUND EFFECTS UPON SOUND PRESSURE LEVELS ON A BOARD FOR WIND TURBINE NOISE MEASUREMENTS

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ABSTRACT
The standard of IEC 61400-11 (Wind turbine generator systems- Part 11: Acoustic noise measurement techniques) provides to mount a microphone with its diaphragm at designated location on a ground board for wind turbine noise measurements. The board could either be circular or rectangular with its minimum width or diameter of 1.0m. These requirements expect to minimize the influence of different ground types. Field experiments to investigate sound pressure level distribution on the board had been carried out to assess how the surrounding ground could affect the measurements. For this purpose, the board was placed on an asphalt surface believed to behave as hard reflecting boundary and on a cut lawn surface with finite impedance. Both sites were enough flat and wide to be regarded as the half free-field. A speaker driven by the white noise signal was used as a sound source and circular ground boards of the diameter of 1.0m, 1.5m and 2.0m were provided for the tests. The results revealed that, while A-weighted measurements were not affected by a size of the board and by the difference of the ground, 1/3 octave band SPL components were affected as large as 3dB by the board size seemingly systematically particularly in mid-frequency range from 50Hz to 5kHz. The results suggest that a size of the board should be restricted to a specific dimension rather than providing smallest dimension and that the microphone be placed at the center of the board rather than off-center location for a circular board, as given in the standard.

1 - INTRODUCTION
In the standard of IEC 61400-11 [1] which prescribes acoustic noise measurement techniques for a wind turbine, a microphone is required to be mounted on a board placed on the ground. The board could either be circular or rectangular with its minimum diameter or width of 1.0 m. Acoustic measurements required in the standard are equivalent continuous A-weighted sound pressure level, octave or one-third octave SPL as well as narrow-band SPL to yield apparent sound power level, wind speed dependence, tonality and so on. Assessments of measurement uncertainty are mandatory and the uncertainties including acoustic conditions for microphone mounting board are required to report.
The purpose of such microphone mounting is to minimize the influence of different ground type on the measurements and to reduce the wind induced noise at microphone. This method was first proposed by Andersen [2] and later accepted by the IEA recommendation [3] as well as by the AWEA standard [4]. However, it is not yet clear how the ground and board size or shape could affect the measurements, and how to assess the type B uncertainty in terms of ground conditions as prescribed in the standard. Thus acoustic experiments have been carried out to evaluate possible influences of the ground and board size upon A-weighted SPL and 1/3 octave band SPL measurements. Two test sites regarded as practically half free field with different boundaries were selected for the experiments; one with hard reflecting surface to serve as the reference and the another covered by cut lawn. The experiments on both sites enabled direct evaluation of the ground and board size effects on the measurements.

2 - TEST SITES AND METHODS
Figure 1 illustrates the outline of experimental setup. A loudspeaker of 50 W rated input which had been lifted 12.0 m above the ground and driven by a white noise signal was used as the sound source. Two

microphones M1 and M2 were used; M1 was located 115 cm from the speaker to serve as the reference; M2 was mounted on the board or partly on the ground surface and moved on the surfaces to obtain sound pressure level distributions. The center of the board was located at the horizontal distance of 18.3 m from the speaker. This arrangement gave the angle of incidence from the speaker to the microphone of around 34 degrees which had followed practical noise measurements of a wind turbine according to the standard [1)].

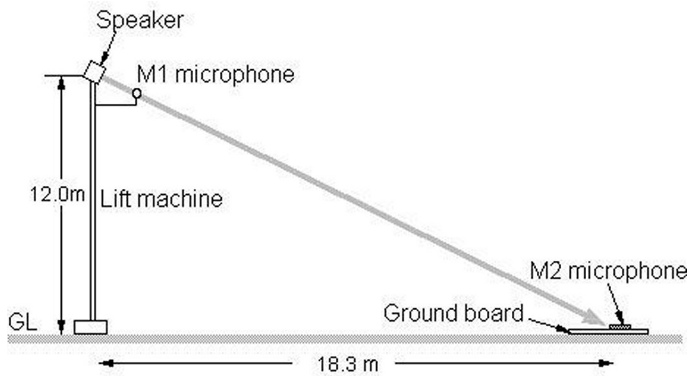


Figure 1: Outline of the experiments.

Three circular boards made of 21 mm thick plywood with diameter of 1.0 m, 1.5 m and 2.0 m were prepared for the experiments. The x-y coordinate was taken on the surface of the board as shown in Figure 2. Sound pressure levels at 28 crossing points of the solid lines together with the standard location shown later were measured using the M2 microphone. Same measurements were also conducted for 1.0 m and 2.0 m diameter boards. The circle mark in the figure is the location of a microphone diaphragm prescribed by the standard [1)]. Of the board with diameter D, the microphone is provided to be located $2D/3$ from the front edge of the board and this position is called the standard location hereafter.

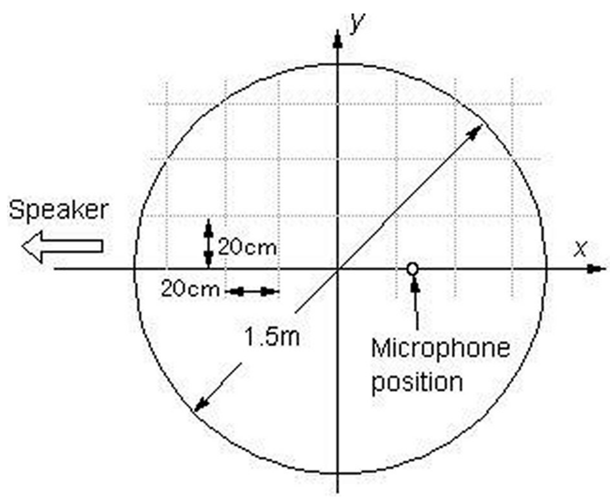


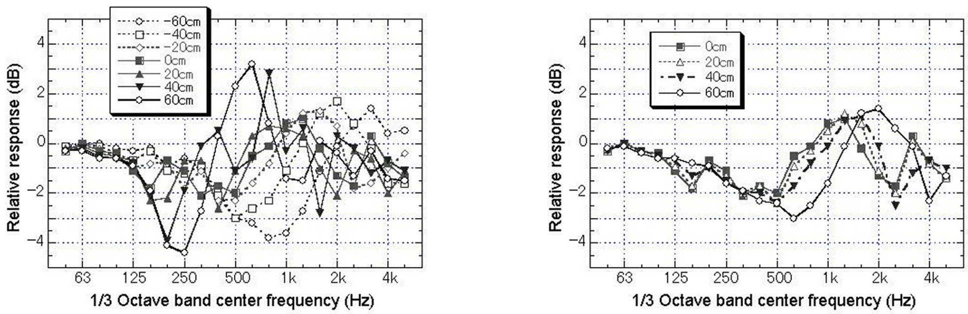
Figure 2: 1.5 m diameter board and coordinate system.

Experiments have been carried out on the steering and handling test facility and the outskirts of collision test facility in the AIST second research center which is located in a rural quite area. The former, cited as site A hereafter, has 200 m by 130 m flat space with asphalt paved surface. This site can be regarded as practical half free space with hard reflecting boundary. Ground surface of the latter, site B hereafter, has half asphalt and cut lawn surface divided by a straight line. There were no sound reflecting structures practically influence the measurements. For the measurements on the site B, the lift machine to which the speaker had been attached was located close to the line on the asphalt side. Surface of the site B was slightly sloped upward in the sound propagation direction. 2 to 3 cm thick sediments of the cut lawn were found covering the soil surface, and 3 to 4 cm height lawns were observed over the sediments. Shear wave velocity of the surface soil and the density were measured to be around 100 m/s and 1.4 g/cm^3, respectively.

3 - RESULTS AND DISCUSSIONS

The ratio M2/M1 of the two microphone outputs was determined for each measurement. First, the reference response $(M2/M)_0$ where M2 microphone was placed directly at the origin of the x-y coordinate on the surface of the site A had been determined. Next, M2/M1 in which M2 microphone had been placed on the board or ground surface was measured to determine the relative response of $M2/M1/(M2/M1)_0$. This response allows us to see directly the effects of surroundings on the sound pressure level distribution on the board.

The relative response of 1/3 octave band frequency for the 1.5m diameter board on the site B are shown in Figure 3 (a) and 3 (b). 0 dB of the relative response means that SPL on the board is exactly the same with that of the output of the microphone directly placed on the site A surface. It is clearly observed that the relative responses fluctuate in the range from -4 dB to +3 dB near the rear edges of the board. Also visible in the figures is the specific feature of fluctuation; the fluctuation occurred systematically such that as the microphone moves up from x=-60 cm to away from the source, the frequency range with large fluctuation move to lower frequencies. It should be noted that the largest level fluctuation occurred at x=60 cm. Further, it is pointed out that level fluctuations along y-axis are roughly the same with each other except the point closest to the edge and that the level of fluctuation at the point is relatively small compared to those of both at x=+/-60 cm.



(a): Along x-axis. **(b):** Along y-axis.

Figure 3: Relative response along x and y-axis on 1.5 m diameter board.

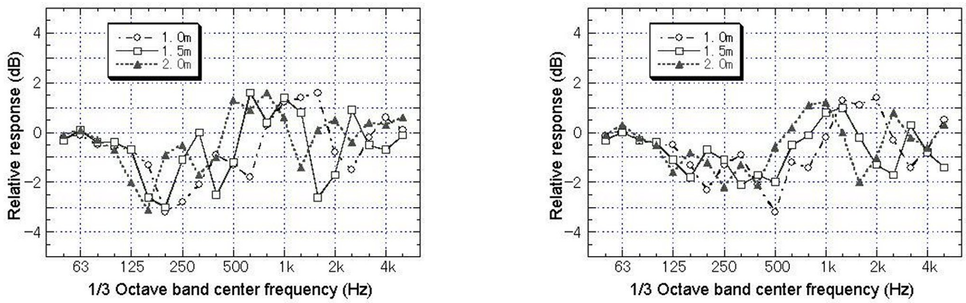
The reason such level fluctuation occurred is believed to be due to the scattering or diffraction of the sound at the edge of the board; scattered or diffracted waves interfered with sound incident to the board from the source to give fluctuations of the level. As previously shown, effects of the scattering seem to appear stronger along the x-axis than that of along the y-axis.

Figure 4 (a) and 4 (b) show the relative responses of the M2 microphone mounted on various sized boards, and the microphone mounted on the center of the board or standard location, respectively. It is clear from these figures that a theory of the larger the board the more accurate the measurements does not necessarily apply and that measurements at the center of the board give smaller fluctuation of the relative response. That the fluctuation of the response at the standard location is larger than that of the center seems simply because the standard location is closer to the rear edge where strong scattering seems to have occurred in specific frequency range. Further, to the question why the size of the board was not effective to improve the measurement accuracy, it could be answered that scattering or diffraction area extended as a line along the edge of the board.

The A-weighted relative responses along the x and y axes on the boards placed on the site B are shown in Figure 5 (a) and 5 (b), respectively. Horizontal axis in these figures is defined by x/r or y/r where r gives the radius of the boards. The A-weighted relative responses were determined subtracting energy summed A-weighted reference response of 50 Hz to 5 kHz components from those of the relative responses for each position on the surface of the boards. It is noted that fluctuations of the A-weighted relative response are small compared to the one-third octave band spectra, and this occurred simply due to the averaging effect of the level with variation at higher frequency range. Also it should be noted that the value of the A-weighted relative response is independent of the board size for wide space on the boards. As far as the A-weighted level is concerned, size of the board and the surroundings around the board have no significant effect on the measurements.

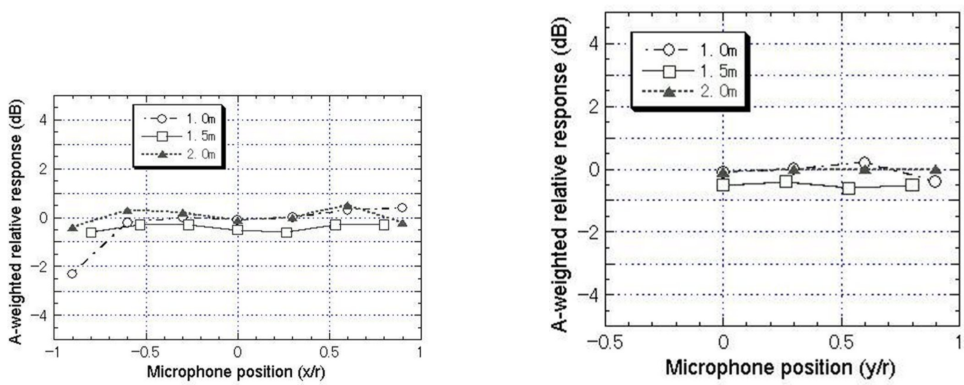
4 - CONCLUSIONS

The sound pressure level distributions on the board placed on the ground due to an obliquely incident sound wave had been carried out at the site which have flat surface covered by lawn to see the ground



(a): Microphone on the standard location. **(b):** Microphone on the center.

Figure 4: Relative response at specific microphone locations on various diameter boards.



(a): Along x-axis. **(b):** Along y-axis.

Figure 5: A-weighted relative response along x and y-axis on the various sized boards.

and board size effect upon the measurements.

The results suggest that as far as the A-weighted measurements are concerned board size and ground effect seemed to be negligible. However, it was found that a few dB of systematic errors is expected for one-third octave band SPL measurements in specific frequency range depending the board size. It was also found that the errors were rather irrelevant to the board size, and a better microphone location turned out to be at the center of the board rather than the standard location.

It was strongly suspected from the experiments not reported here that the discontinuity inevitably created between the surface of the ground soil and the board plays an important role for the spectrum error. Because immediate countermeasure to such problems seems difficult, it is recommended to restrict the board to a specific size and shape to enable measurements to acquire reproducible data with consistency for a future revision of the standard.

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