Evaluation on the Numerical Simulation Model of Wind Speed Distribution behind the Offshore Wind Power Generation Used Observed Data

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1. Introduction

The amount of wind power generation aims for three millions kWh by 2010 in Japan. It is very few offshore construction in Japan compared with European countries. It is generally said that offshore wind energy is greater than in land area, and few disturbance. In Japan, suitable construction sites for wind power generation in land are decreasing, then, the construction of wind power generation in port and coastal area is strongly hoped.

The first offshore wind power generation in Japan was completed at the port of Setana, Hokkaido in 2004. The size of wind power generation is 600 kW and the numbers of wind generators are two. Field observation on wind speed distribution was carried out by the Wind Power Generation Research Association for Port and Coastal Area organized in Coastal Development Institute of Technology (CDIT), Japan. This paper describes on the wind speed distribution behind the offshore wind power generation by use of the filed observation carried out at the port of Setana and the result of numerical simulation on the wind speed distribution. Field observation was carried out in February, 2004. The measuring of wind speed was carried out by use of the laser radar installed on the land. The accuracy of measured data was calibrated by observed data by wind cup pattern anemometer installed on the breakwater. The profiles of vertical wind speed distribution at the offshore site are examined by use of observed data. And also the numerical simulation model and its parameter on the ratio of sheltering effect by the wind power generation are examined.

2. Wind observation at the port of Setana

2.1 Offshore wind firm in the port of Setana

The first offshore wind power generation was completed at the port of Setana, Hokkaido, Japan. **Photo 1** shows the wind power generation. Two wind power generators of 600 kW were installed behind the breakwater. The foundation is the dolphin structure supported coupled piles. The diameter of rotor is 47m and the height of hub is 40m. Cut-in and cut-off wind speeds are 4m/s and 25m/s, respectively.

Photo 2 shows the layout of the port, the arrangement of wind power generations and the observation system of wind speed and wind direction. The number 1 in the figure is wind power generation, the number 2 and 4 are wind speed meter installed on the breakwater and in land, respectively. The number 3 is the position of laser radar.

2.2 Method of observation

a) Observation system

Photo 3 shows the appearance of laser radar. The system is composed of a main unit, a sensor head, and a computer [1]. The single wavelength laser of safe 1.5 μm to the eye is made to occur in the main unit. It is transmitted into the atmosphere through the fiber-optic cable from the sensor head. After it is collected by the sensor head, scattered light from aerosol in the atmosphere is sent to the body parts with a fiber-optic cable. And the Doppler shift of the transmission and reception light is detected in the main unit. The movement speed of aerosol is calculated in the computer from Doppler shift, and the wind speed and direction is found. The measured wind speed and direction by laser radar is good accordance with observed one by wind cup pattern anemometer and arrow wing pattern wind vane [1].

Photo 1 Wind power generation

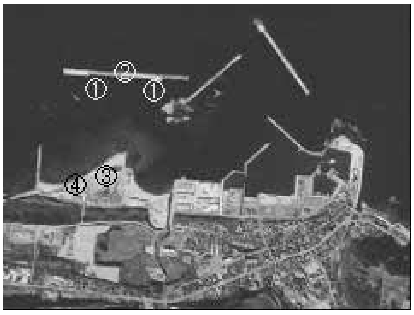


Photo2 Layout of the port of Setana

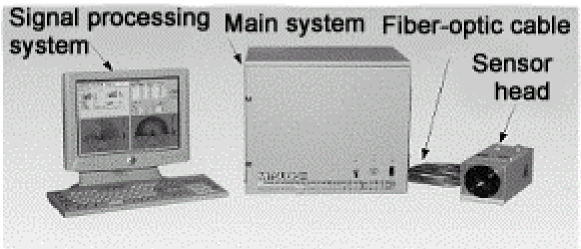


Photo3 Observation system

b) Observation layout

Figure 1 shows the area of wind speed observation behind wind generators. Wind speed is observed at the locations of 2.5, 5.0, 7.5, 10.0 times of the diameter of rotor. Observed lines are behind lines of two wind generators and the center line of two generators.

Figure 2 shows the layout of breakwater and wind power generator. It should be considered the interaction effect of breakwater and wind power generators in the modeling of computation of wind speed distribution.

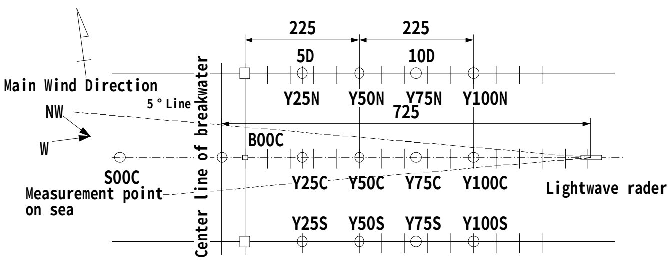


Figure 1 Location of observed points

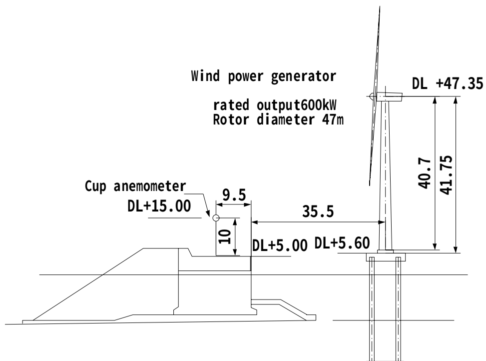


Figure 2 Breakwater and wind power generator

3. Result of observation

3.1 Wind speed and direction during observation

Figure 3 shows wind speed and direction observed by use of wind cup type anemometer and arrow wing pattern wind vane during February 18th to 20th, 2004. Upper and lower figures show wind direction and wind speed, respectively. Wind speed in February 18th was greater than 10m/s and offshore wind (NW, 315degrees). Wind speed during the mid night and early morning of February 19th became low and a land wind.

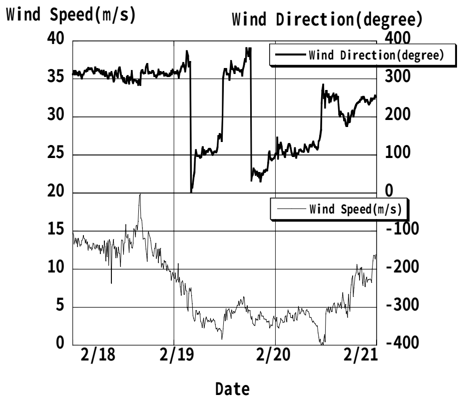


Figure 3 Wind speed and direction during observation

Figure 6 Area of numerical simulation

3.2 Vertical profile of wind speed

The vertical wind speed distribution between DL+15m to DL+205m was observed on the sea at the 1000 meters distance from the land. The observation was carried out during 6 seconds for each elevation and repeated alternating measuring points automatically. **Figure 4** and **Figure 5** shows wind speed distribution of February 18th and 20th, respectively. Normalized wind speed at DL+15 m were 12.6 m/s in February 18th and 4.6 m/s in February 20th, respectively.

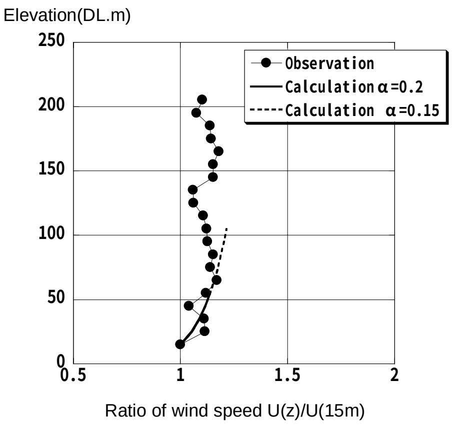


Figure 4 wind speed profile (Strong wind, Feb. 18th)

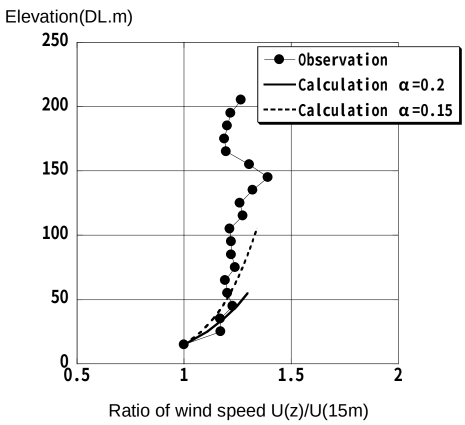


Figure 5 Wind speed profile (Weak wind, Feb. 20th)

By comparing vertical profile of wind speed between measured one and computed by exponential law, the parameter agrees well in 0.15 to 0.2. And vertical distribution higher than DL+50m seems constant. Boundary layer on the sea seems thin compared with in land. This mean offshore site is good at for wind power generations.

4. Numerical simulation of wind distribution

4.1 Numerical modeling

In the numerical simulation of wind speed distribution around wind power generations, the generators are treated as obstacles in the space. The additional term F_i, which is related to reduction effect of wind speed behind like as trees, is considered in the numerical simulation.

$$\frac{\partial\langle u_i\rangle}{\partial t}+\frac{\partial\langle u_i\rangle\langle u_j\rangle}{\partial x_j}=-\frac{\partial}{\partial x_i}\left(\frac{\langle p\rangle}{\rho}+\frac{2}{3}k\right)+\frac{\partial}{\partial x_j}\left\{\nu_t\left(\frac{\partial\langle u_i\rangle}{\partial x_j}+\frac{\partial\langle u_j\rangle}{\partial x_i}\right)\right\}-\underline{\underline{F_i}} \quad (1)$$

$$F_i = \eta C_{fi}\langle u_i\rangle\sqrt{\langle u_j\rangle^2} \quad (2)$$

Where,$\langle u_i \rangle$is three component of wind speed, k is energy of flow, ε is dissipation , $\langle p \rangle$ is pressure and ρ is density of air, η is parameter evaluating sheltering effect.

The area of simulation around wind power generations is shown in **Figure 6** [2]. The horizontal mesh size in the model is 22.5 meter each and the total grid number is 60 by 60. The mesh for vertical elevation is divided to six layers of 10 meter interval between 5m to 55m from ground level and ten layers between 55m to 300m.

The wind energy generators are modeled 1 by 2 mesh in horizontal, and also the 4^{th} to 7^{th} layer in vertical direction. The roughness of surface for sea and land is set 0.001m, 0.2m, respectively. The roughness of a breakwater and a small island in the port is also used the same value for land.

4.2 Case of computation

Two cases listed in **Table 1** are computed in this research. Case 1 is corresponding to the strong wind and Case 2 to weak wind.

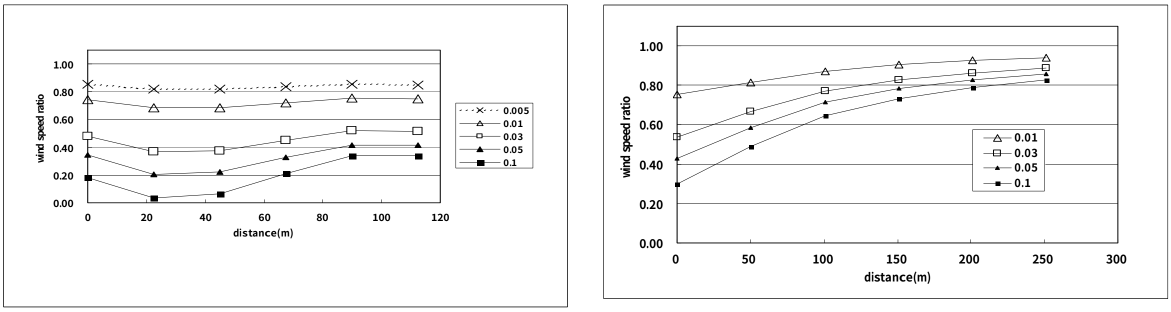
Table 1 Computation case

Case	Time	Wind Direction and Wind Speed (Above Breakwater 15m)
1	Feb. 18^{th} 13:10-14:00 15:20-15:30	WNW 12 - 15 m/s
2	Feb. 19^{th} 13:30-13:50 16:30-16:50	NNW-N 4 - 6 m/s

Observed wind speed ratio behind wind power generations are 0.93 to 1.0 for generator 1 and 0.88 to 0.98 for generator 2 in strong wind case. And the ratio is 0.77 to 0.84 for generator 1, 0.70 to 0.79 for generator 2 in weak wind case.

4.3 Effect of parameter of wind sheltering

The parameter of sheltering effect is discussed by alternating the parameter. **Figure 7** shows the wind speed distribution behind wind power generator. In the figure, the result obtained when the parameter is set 0.01, 0.03, 0.05, and 0.1, respectively. In the case of strong wind the result by the parameter 0.005 is additionally shown in the figure. In case of weak wind, the wind speed distribution behind wind power generator is decreased to about 0.75 and recovered to about 0.9 at the 100 meter behind the generators when the parameter is 0.01. It is agree well to the observation. In case of strong wind, the wind speed ratio remains less than 0.8, so the parameter shall be set 0.005.

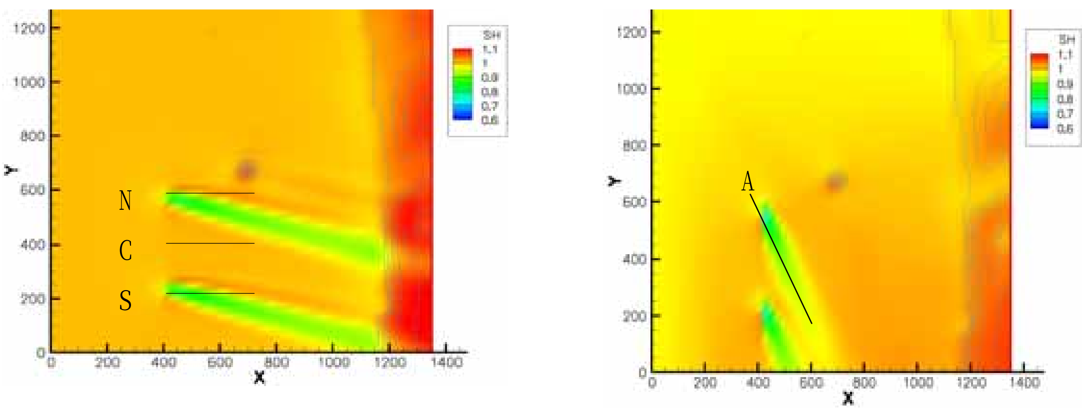


(1) Strong wind (2) Weak wind

Figure7 The relation of parameter and wind speed distribution

4.4 Wind speed distribution behind wind generator

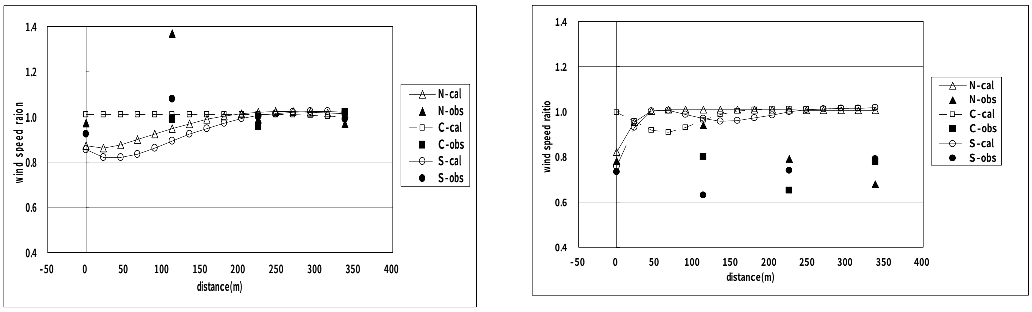
Figure 8 shows horizontal wind speed distribution obtained by numerical simulation at 45m from sea level, where is close to the height of hub. The parameter of sheltering effect is set for 0.005 for strong wind case and for 0.01 for weak wind case. In strong wind case, the wind speed reduction behind wind generators is more than 0.8. The wind speed reduction by wind generator is not so large, but the effecting area is relatively large behind wind generators. In the case of weak wind, the wind speed reduction around the wind generators decreased to 0.7, but the sheltering effect is limited to the area around wind generators.



(1) Strong wind (2) Weak wind

Figure 8 Horizontal wind speed distribution (45m above the sea level)

Figure 9 shows the comparison of horizontal wind speed by numerical simulation and observation for the lines of N, C, S, respectively. **Figure 10** shows the vertical profile of wind speed distribution for the line A, which is SSE wind direction. In strong wind, the result of numerical simulation agrees well to observed data. In weak wind, the result of numerical simulation agrees well at neighbors of wind power generator. There are large differences at the area apart from the generators. The wind ratio, however, becomes around 0.8 in the line A. Then, the data obtained by numerical simulation seems almost same as observed one.



(1) Strong wind (2) Weak wind

Figure 9 Wind speed ratio behind wind generator

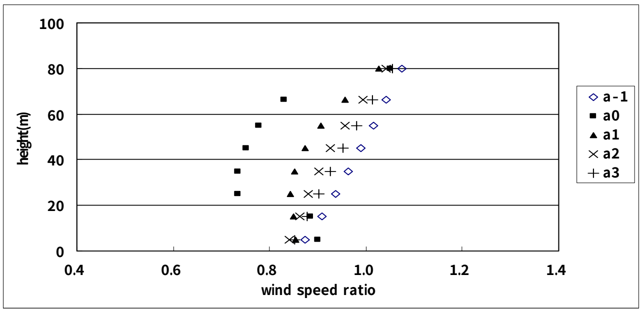


Figure 10 Vertical profile of wind speed

5. Conclusion

The conclusions in this research are as follows.

1) The vertical profile of wind speed is obtained around the breakwater in the port. The parameter in exponential law agrees well in 0.15 to 0.2. And vertical distribution higher than DL+50m is constant.

2) The parameter of numerical model of wind speed distribution around offshore wind power generation is examined by means of field observed data. The model can evaluate the reduction of wind speed behind the wind power generation.

3) The model shall be applied the planning of layout and the arrangement of wind power generators.

References

[1] K. Nishi, S. Shiraishi, M. Hamano, Y. Umeki, H. Kume: Survey report of offshore wind conditions in prospect of offshore wind energy conversion systems in Japan, Proc. of OCEANS' 04 MTS/IEEE TECHNO-OCEANS '04, pp.1830-1834, 2004.11

[2] S. Shiraishi, T. Nagai, H. Hayashi, K. Nishi H. Kume, S. Dohata: Evaluation on the wind speed distribution behind offshore power generation used field data obtained at the port of Setana, Annual Journal of Civil Engineering in the Ocean, JSCE, Vol.21, pp.1059-1064, 2005.7 (in Japanese)