METOCEAN MEASUREMENT AT FUKUSHIMA OFFSHORE SITE

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Metocean measurement at Fukushima test site was carried out and metocean characteristics were investigated. The effect of met mast tower on the measured wind speed can be mitigated by using the CFD simulation. Furthermore, the corrected wind speed data from the cup anemometer show good agreement with the wind speed measured by Lidar. The prevailing wind direction is NNW in winter and SSW in summer. The spectral significant wave height and period measured by wave buoy show good agreement with the statistical significant wave height and period measured by the wave meter. The prevailing wave direction is easterly all through the year. The current speed and direction measured by ADCP and wave meter show good agreement. The prevailing current direction is southbound cause by local current (*Oya-shio*)

Keywords: metocean measurement, metocean characteristics

INTRODUCTION

For the planning the design of floating offshore wind farm, the investigation of metocean condition including the sea current is important. In this study, metocean measurements were carried out at Fukushima Offshore test site as a part of the Fukushima Floating Offshore Wind Farm Demonstration (Fukushima FORWARD) project [1, 3] by using the measurement devices installed on the floating substation and wave buoy. Measurement data obtained from multiple devices are cross-validated and missing data are compensated by using the data measured by the other device to generate complete and consistent data sets for one year. Then the metocean characteristics of the site is investigated.

OUTLINE OF THE MEASUREMENT SYSTEM

Offshore met mast is located on the floating substation, 20km offshore the Fukushima Coast, where the water depth is 120m as shown in Fig.1. Fig. 2 shows the met mast on the substation.

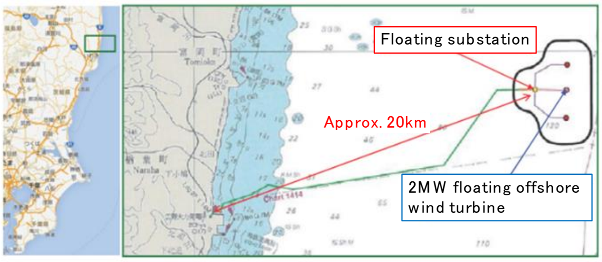


Fig. 1. Fukushima offshore site.

Multiple measurement devices are employed to measure each metocean parameter to ensure the reliability of the system. This also allows to cross validate the measured data to decrease the uncertainty of the measurement. Table 1 and Fig.3 show the list of the measurement devices.

Three sets of cup anemometers and wind vanes are installed with the horizontal interval of 120 degree to minimize the effect of the tower itself, at three different heights (40m, 50m and 60m above sea level). An additional wind vane is installed at the top of the tower to measure the unaffected wind direction, which is used to decide which anemometers can be used. A Doppler Lidar is installed on the deck, which measures wind speed and direction from the height 60m to 290m above sea level.

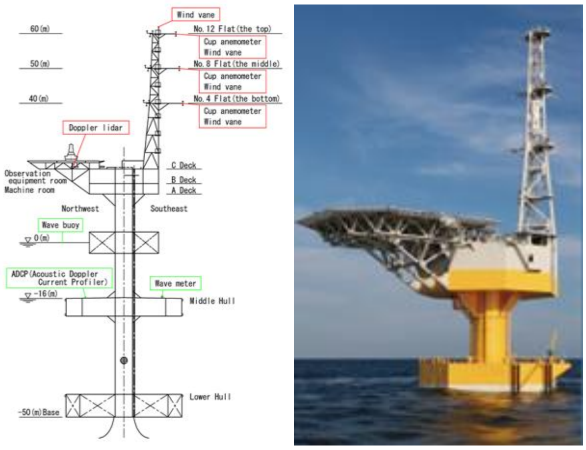


Fig. 2. Schematic and overview of the substation

Table 1. The list of the measurement device
(a) meteorological measurement device

parameter	device	location
wind speed	cup anemometer	met mast
wind direction	wind vane	met mast
wind speed wind direction	doppler lidar	deck

(b) oceanography measurement device

parameter	device	location
wave height wave period	wave buoy	500m from substation
wave height wave period current speed current direction	wave meter	middle hull
current speed current direction	ADCP	Middle hull

A wave meter and an ADCP are installed on the middle hull of the substation and a wave buoy is installed on the sea 500m from the substation.

Fig. 3. Metocean measurement device system

WIND DATA

Wind data measured by the cup anemometer installed on met mast is affected by met mast itself. Computational fluid dynamics (CFD) simulations around the mast is carried out to investigate the effect of the met mast. The CFD simulation is validated by using the relative wind speeds measured at three anemometers on the same height. Fig.4 shows the calculated wind field. The wind speed decreases significantly at the leeside of the tower and increases at the side of the tower. Slight decrease of the wind speed can be seen upstream of the tower. Fig.5 shows the wind speed ratio between two anemometers as a function of the wind direction at the height of 50m above sea level. When one of the anemometers is in the wake of the tower, the wind speed ratio decreases or increases significantly. Even when none of them is in the wake, the effect of the tower is no negligible giving higher of smaller value of wind speed ratio than 1.0. In any wind direction, CFD results show good agreement with measurements.

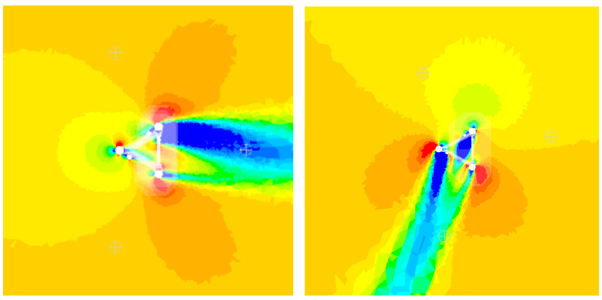


Fig. 4. Flow field simulated by CFD

To estimate unaffected wind speed, this CFD result was used. The wind speed measured at the cup anemometer located upstream of the tower is used and depending on wind direction, speed up ratio calculated by CFD simulation was considered to estimate the unaffected wind speed. The wind vane located at the top of the tower, the wind direction measured by which is not affected by the tower, is used to decide the wind direction.

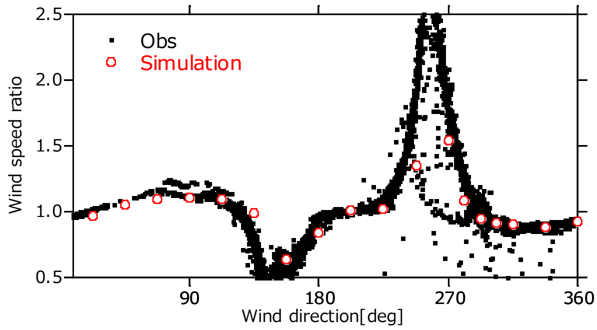
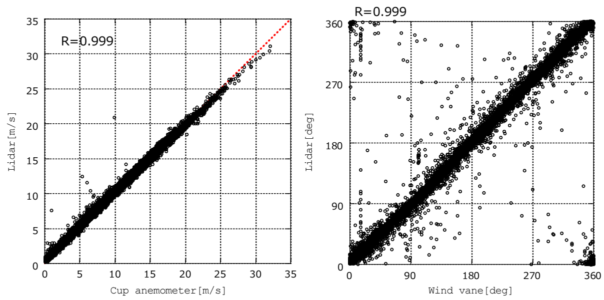


Fig. 5. Directional wind speed ratio

Corrected wind speed and direction and the results of the doppler lidar were compared at 60m above sea level, where, both measurements are available (Fig. 6). Both wind speeds and directions are consistent. In this study, wind data measured by Lidar (u_{Lidar}) is considered to be accurate, and when data from Lidar is missing, the wind speed measured by the cup anemometer (u_{Cup}) is used considering the sight difference between them (Eq.(1)).

$$u_{\mathrm{Lidar}} = a u_{\mathrm{Cup}} + b \tag{1}$$

$$a = 0.99; \quad b = 0.3$$



(a) Wind speed (b) Wind direction

Fig. 6. Comparison between cup anemometer and Lidar

WAVE DATA

The data obtained by wave buoy includes the unexpected peak in low frequency part of the spectrum. Fig.7 shows such an example. This is probably some problem in the measurement and in this study, if the peak period is longer than 24.9s (frequency is lower than 0,04Hz), the data is treated as missing.

The evaluation time of the wave spectrum in the wave buoy is 30 minutes and the evaluation time of significant wave period in the wave meter is 20 minute. On the other hand, the international standard IEC 61400-3[2] specifies the evaluation time of 60 minutes. In this study, the wave statistic measured by the wave buoy and the wave meter are converted into 60 minutes value. Fig.8 shows the comparison between spectral significant wave height (H_s) and statistical significant period (or sometimes called energy period, $T_{m-1,0}$) obtained by the wave buoy and statistical significant wave height ($H_{1/3}$) and significant wave period ($T_{1/3}$) obtained by wave meter. The statistical and spectrum wave statistics show fairy good agreements. In this study these wave statics are considered to be equal.

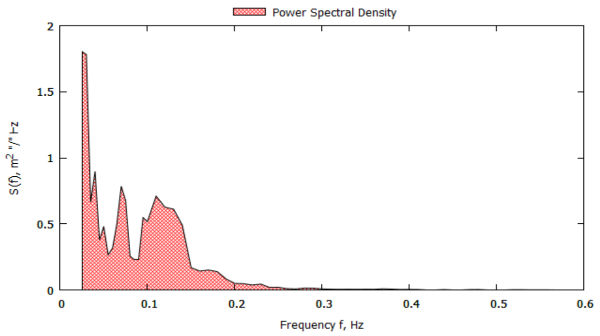
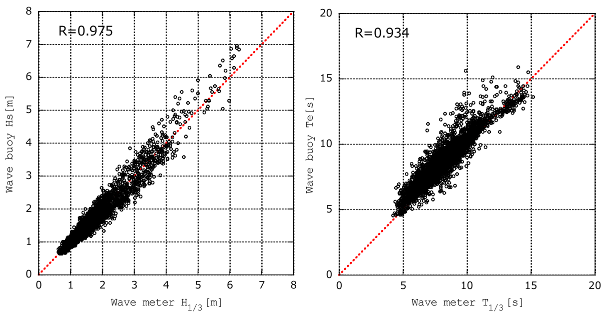


Fig. 7. An example of unexpected spectrum measured by the wave buoy (2015/06/25 5:42)



(a) Wave height (b) Wave period

Fig. 8. Comparison between wave buoy and wave meter

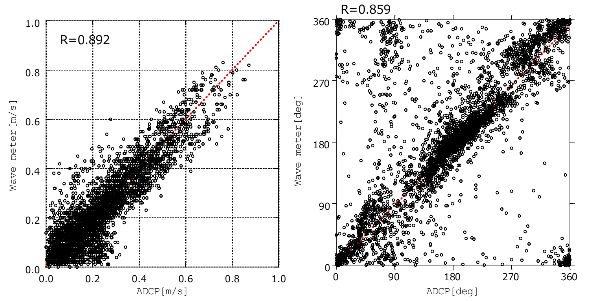
Wave data measured by the wave buoy is used because of better availability. If data is missing, the wave data measured by the wave meter is used. Table 2 shows frequency distribution table of wave height and wave period. The highest frequency occurs when the significant wave height is between 1.00m and 1.25m and significant wave period is between 8s and 9s.

Table 2. Frequency distribution table of wave height

Wave height \ Wave period	0.0～	1.0～	2.0～	3.0～	4.0～	5.0～	6.0～	7.0～	8.0～	9.0～	10.0～	11.0～	12.0～	13.0～	14.0～	15.0～	16.0～	Frequency occurrence	Frequency rate[%]
7.00～																		0	0.0
6.50～7.00														2	5			7	0.1
6.00～6.50												1		2	1	1		5	0.1
5.50～6.00												1	1	5	2	1		10	0.1
5.00～5.50										2	3	1	4	4	4			18	0.2
4.50～5.00										3	6	1	1	15	2	1		29	0.3
4.00～4.50								1	4	21	10	5	8	12	1			62	0.7
3.50～4.00								4	22	46	43	25	25	18	2	1		186	2.1
3.00～3.50								7	30	66	76	30	17	13				239	2.7
2.50～3.00							23	55	115	154	76	16	16	5				460	5.3
2.00～2.50						7	94	180	317	131	81	63	23					896	10.2
1.75～2.00						14	76	208	238	169	69	21	3					798	9.1
1.50～1.75						41	140	338	338	187	138	28	10					1220	13.9
1.25～1.50					4	72	210	423	360	297	89	36	6					1497	17.1
1.00～1.25					8	119	223	526	450	230	27	8						1591	18.2
0.75～1.00					17	110	247	419	418	153	9	2						1375	15.7
0.50～0.75					2	36	98	149	73	7	1							366	4.2
0.25～0.50									1									1	0.0
～0.25																		0	0.0
Frequency occurrence	0	0	0	0	31	399	1111	2310	2366	1466	628	238	114	76	17	4	0	8760	100.0
Frequency rate[%]	0.0	0.0	0.0	0.0	0.4	4.6	12.7	26.4	27.0	16.7	7.2	2.7	1.3	0.9	0.2	0.0	0.0	100.0	

CURRENT DATA

Current speed and direction measured by wave meter and ADCP are shown in Fig.9. The data measured by wave meter is measured at 11m below sea level and 20minutes average value. The data by ADCP is measured at 11.78m below sea level and also averaged over 20 minutes. Both measurements show fairy good agreement. In this study, current data by wave meter is used because of better availability. If the data is missing, the data measured by ADCP is employed.



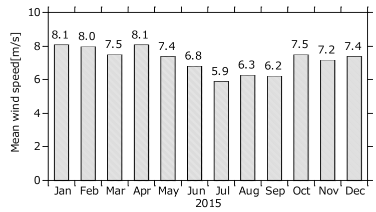
(a) Current speed (b) Current direction

Fig. 9. Comparison between wave meter and ADCP

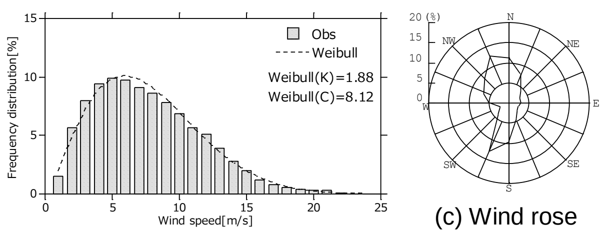
METOCEAN CHARACTERISTICS AT FUKUSHIMA OFFSHORE SITE

The metocean characteristics at Fukushima offshore site is investigated based on the measurement from January to December in 2015.

The statistical of the wind data is shown on Fig.10. Monthly mean wind speed at 60m height is between 5.9m/s and 8.1m/s and annual mean wind speed is 7.2m/s. The prevailing wind direction at 60m above sea level is NNW and SSW. The SSW wind accounts for 12.9% and typically seen in summer and NNW wind accounts for 12.6% and dominant in winter.



(a) Monthly mean wind speed



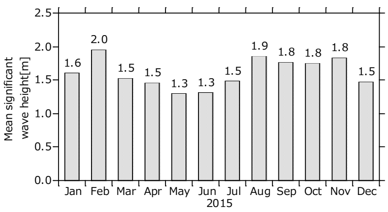
(c) Wind rose

(b) Wind speed frequency distribution

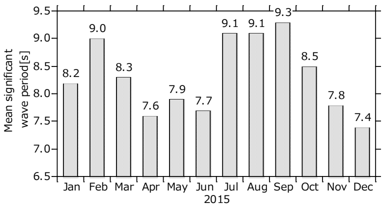
Fig. 10. Statistical wind data (+60m)

The statistics of the wave data is shown on Fig.11. Monthly mean significant wave height is between 1.3m and 2.0m and annual significant wave height is 1.6m. Monthly mean significant wave period is between 7.4s and 9.3s, Due to the influence of swell from Pacific Ocean, the significant wave period shows large value all through the year. The prevailing wave direction is easterly, which means wave generally comes from the Pacific Ocean. The most frequent wave period is between 8s and 9s, with the frequency of 27%. The frequency of occurrence of significant wave period shorter than 5s accounts only 0.4%. The highest frequency of significant wave height can be found between 1.00m and 1.25m with the frequency of 18.2%. The case where the wave height is smaller than 0.5m, is very few.

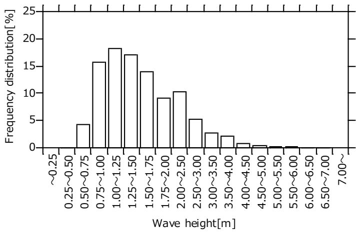
The statistics of the current are shown in Fig.12. Monthly mean current speed at 11m below sea level is between 0.09m/s and 0.31m/s and annual mean current speed is 0.18m/s. The southbound current direction is dominant, which is caused by the local ocean current, *Oya-shio*.



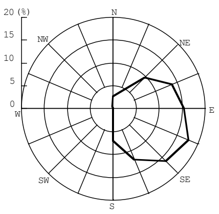
(a) Monthly mean significant wave height



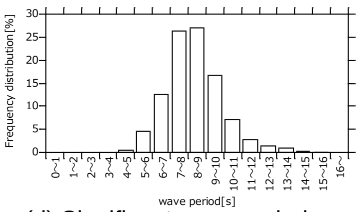
(b) Monthly mean significant wave period



(c) Significant wave height frequency distribution



(e) Wave rose



(d) Significant wave period frequency distribution

Fig. 11. Statistical wave data

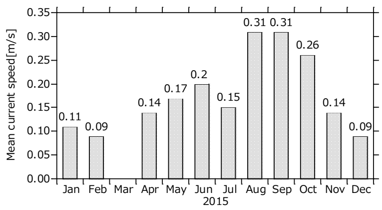
CONCLUSIONS

In this study, metocean measurement at Fukushima test site was carried out and metocean characteristics were investigated. Following conclusions are obtained.

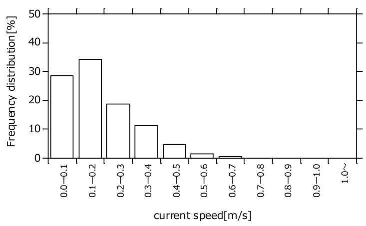
1) The effect of met mast tower on the measured wind speed can be mitigated by using the CFD simulation. Furthermore, the corrected wind speed data from the cup anemometer is same as that from the Lidar. The prevailing wind direction is NNW in winter and SSW in summer.

2) The spectral significant wave height and period measured by wave buoy show good agreement with the statistical significant wave height and period measured by the wave meter. The prevailing wave direction is easterly all through the year.

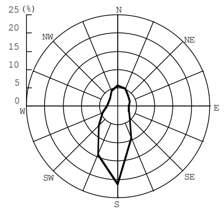
3) The current speed and direction measured by ADCP and wave meter show good agreement. The prevailing current direction is southbound cause by local current (*Oya-shio*)



(a) Monthly mean current speed



(b) Frequency distribution of current speed



(c) Current direction frequency distribution

Fig. 12. Statistical current data

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