COMPARISON BETWEEN MEASURED VALUE AND SIMULATED VALUE OF MOTION AND MOORING FORCE IN MITSUBISHI 7MW FLOATING OFFSHORE WIND TURBINE

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The demonstration project of the floating offshore wind farm " Fukushima FORWARD" is ongoing [1]. Mitsubishi 7MW floating offshore wind turbine (FOWT) was installed at about 20 km far from seashore on October 2015. This FOWT has the V-shaped semi-submersible floating structure and is moored by 8 large caliber catenary chains. The motions of floater and the mooring forces are continuously measured by GPS units, gyro meters and inclinometers specially made for large mooring chains. The demonstration data in severe conditions have been accumulated, for example, the motion and mooring force data during some severe typhoons. These demonstration data are used to validate the design loads, motions and mooring forces. In this paper, the stability of FOWT is investigated by the comparison between the measured value and simulated value, and it is concluded that the V-shaped semi-submersible floating structure is stable and appropriate for large floating offshore wind turbine.

Keywords: renewable energy, FOWT, mooring force, V-shaped semi-submersible floating structure

V-SHAPED SEMI-SUBMERSIBLE FLOATING STRUCTURE

The V-shaped semi-submersible floating structure was developed as the stable floater for 7MW wind turbine, based on the technology and knowledge of ocean engineering in Mitsubishi Heavy Industries, LTD. (MHI) [2][3]. This floater is designed in such a way that two rectangular parallelepipeds (lower hull) are arranged in V-shape and three rectangular parallelepipeds (columns) are arranged at the ends of the lower hull. During the installation process of wind turbine, this floater can have a shallow draft, which is suitable for towing from harbor. At the operation site, this floater should be in semi-submerged condition. Fig. 1 shows the location of Mitsubishi 7MW FOWT and Fig.2 shows the picture of this FOWT during operation. The principal dimensions are shown in Table 1.

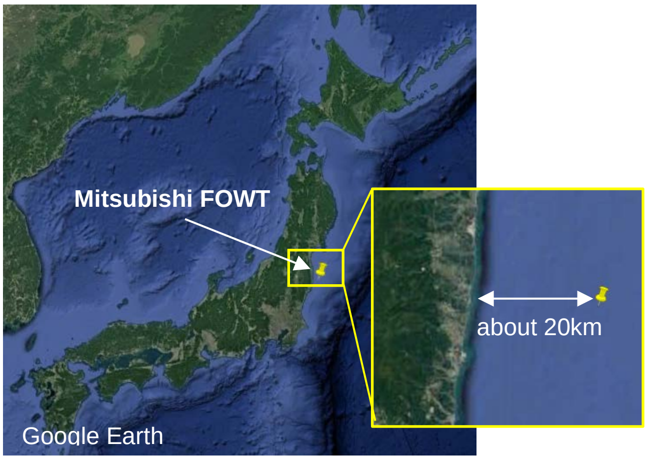


Fig. 1. Location of Mitsubishi 7MW FOWT

Table 1. Principal dimensions

Rotor diameter	167	m
Hub height from sea surface	105	m
Length floating structure	85	m
Width floating structure	150	m
Column width	14	m
Draft	17	m
Displacement	26,000	ton

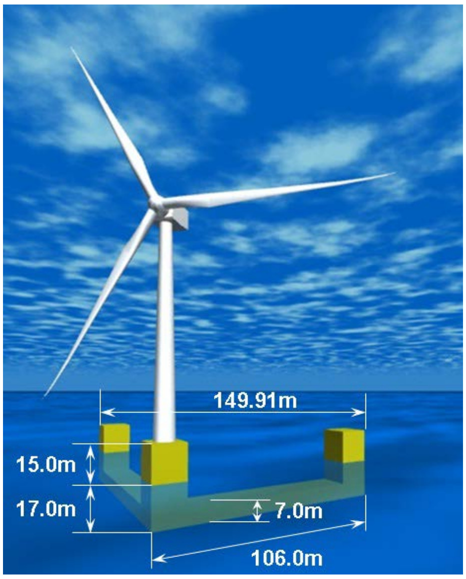


Fig. 2. 7MW wind turbine and V-shaped semi-submersible floating structure

MEASUREMENT SYSTEM

The position and motion of the floater are measured by GPS (Global Positioning System), Fiber Optic Gyroscope, accelerometers and satellite compasses. Among them, the GPS measurements have the high accuracy by the high speed communication with the base stations onshore. The stresses at cross sections of the hull structure are monitored by strain gauges. The inclinations of mooring chains are measured by inclinometer attached to these chains. The inclinometer has a small inertial sensor inside the pressure resistant case, and is developed specially for these mooring chains. The sampling frequency of all equipment is set 20 Hz and this measurement system has operated since November 2015. The image of sensor arrangement is shown in Fig. 3.

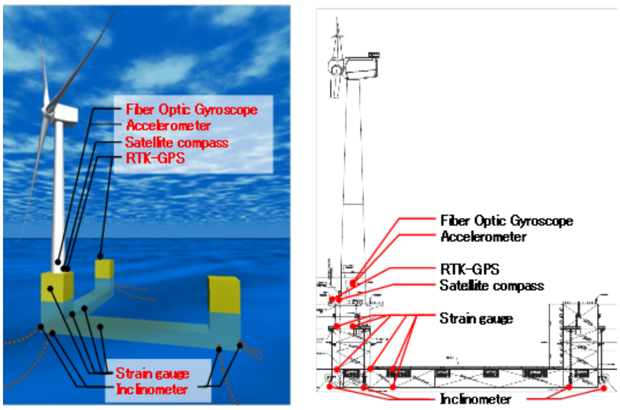


Fig. 3. Sensor arrangement

EVALUATION OF VALIDITY FOR DESIGN

Target conditions to validate design method

Since this measurement system started to operate, some storms with high speed and high wave height have occurred. In this paper, we focus on the storm (typhoons in August 2016) and the rated operation of 7MW in December 2017.

Motion analysis programs

The motion analysis program developed by MHI was used for simulations. In this program, motions of the floater are derived from solving the equation of motion in the time domain. The equation of motion consists of the irregular external forces of wind and wave, the fluid forces calculated by the linearity potential theory, the mass, the restoring force of mooring chains and so on.

Mooring forces in storm conditions

In order to validate the stability of mooring design, simulations were carried out under storm conditions using the motion analysis program.

The target storm conditions are the typhoon No.9 (Mindulle) and the typhoon No.10 (Lionrock) in 2016. The highest wind speed during the observation period was observed in the typhoon No.9. The highest wave height was observed in the typhoon No.10. The paths of the typhoon No.9 and No.10 are shown in Fig. 4. The typhoon No. 9 had passed about 55km west of Mitsubishi FOWT and the Typhoon No.10 had passed about 90km east of Mitsubishi FOWT.

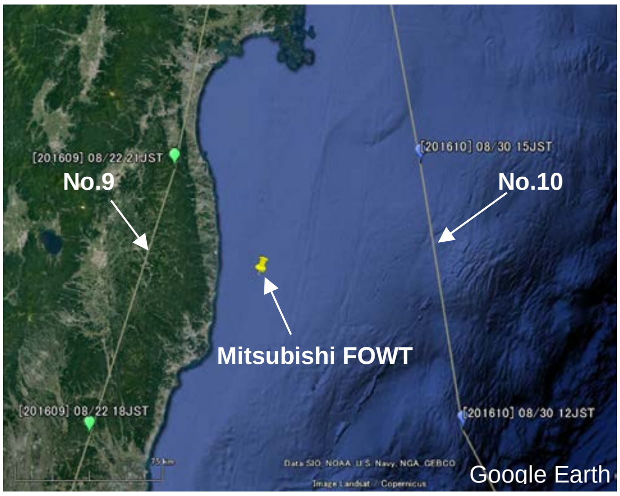
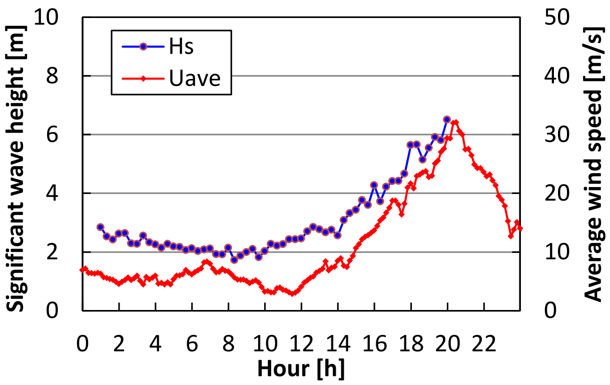


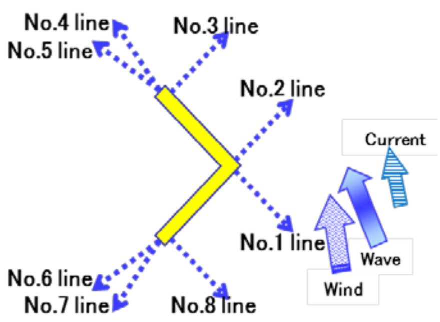
Fig. 4. Paths of typhoon No.9 and No.10

The comparison between the maximum mooring force of measured data and simulation results are shown in Fig. 5 and Fig. 6. In these figures, Uave means the 10 minutes average wind speed, Hs means the 20 minutes significant wave height and Vcr means the 20 minutes average current speed.

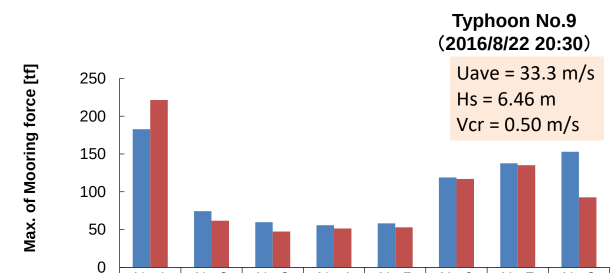
Fig. 5 and Fig. 6, (a) show the time series of Hs and Uave at the wind farm during the typhoon No.9 and No.10. During the typhoon No.9 case, the maximum values of Uave and Hs were measured at around 20:30. (However, there is measurement error for Hs after 20:00.) In the typhoon No.10 case, the maximum value of Hs was measured at around 12:50. Fig. (b) shows the directions of wind, wave and current. During the typhoon No.9 case, these external forces were acting in nearly same direction, whereas for typhoon No.10, these forces were acting in different directions. (c) shows the comparison result of mooring forces between measured values and simulated values. The simulation results show the higher value than the measured data, hence the simulation can estimate the mooring force in safe side.



(a) Time series of Hs and Uave on 2016/8/22



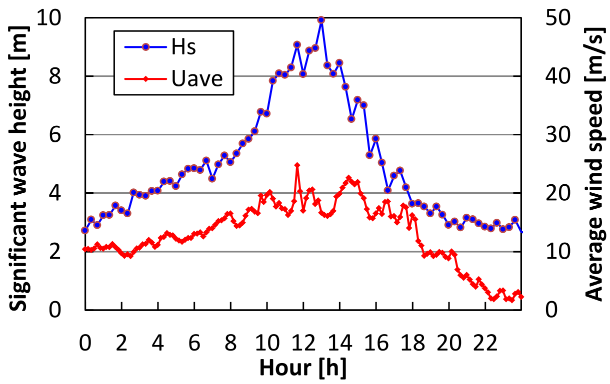
(b) Directions of wind, wave and current



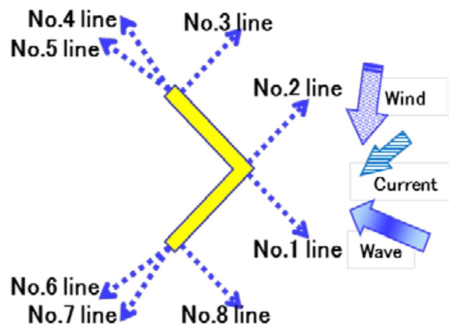
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Measured [tf]	182.8	74.3	59.7	55.8	58.3	118.9	137.8	153.0
Simulation [tf]	221.4	61.7	47.4	51.4	53.0	117.1	135.2	92.7

(c) Comparison of mooring forces in storm conditions

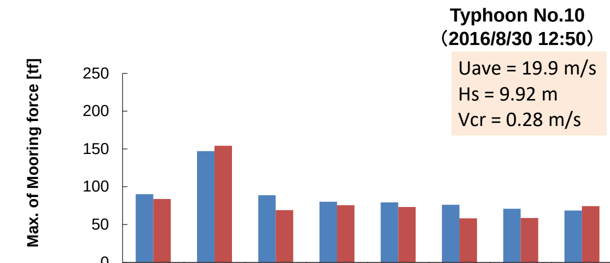
Fig. 5 Result of analysis for the typhoon No.9



(a) Time series of Hs and Uave on 2016/8/30



(b) Directions of wind, wave and current

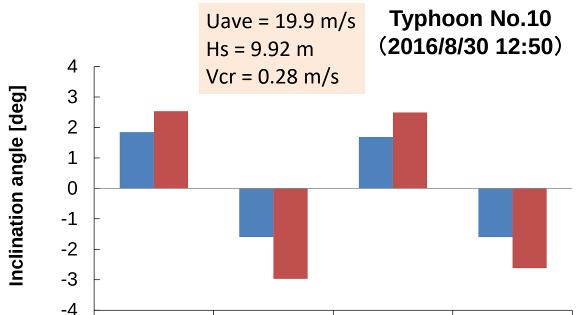


	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Measured [tf]	90.2	147.2	88.8	80.2	79.4	76.2	70.9	68.5
Simulation [tf]	83.9	154.2	69.1	75.6	73.3	58.2	58.7	74.4

(c) Comparison of mooring forces in storm conditions

Fig. 6 Result of analysis for the typhoon No.10

In the Fig. 7, the measured floater pitch and roll motions are compared with the simulation results in the typhoon No.10. The simulated floater motions were calculated by the motion analysis program. During this typhoon, the highest wave height (9.92m) was observed, though, the maximum pitch motion in the typhoon No.10 confirmed to be below 3 degree.

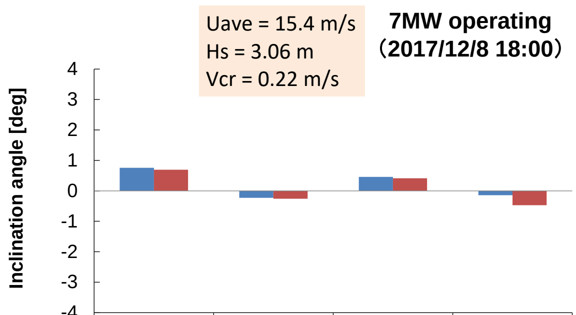


	Max Simulation	Min Simulation	Max Measured	Min Measured
Roll [deg]	1.85	-1.60	1.69	-1.60
Pitch [deg]	2.53	-2.97	2.49	-2.62

Fig. 7 Comparison of floater motion in the typhoon No.10

Floater motions in 7MW operating conditions

In the Fig. 8, the measured floater pitch and roll motions are compared with the simulation results in the 7MW operating conditions. During the 7MW operation, the range of these motions is within +1 degree to -1 degree. Considering the floater motion in the 7MW operation conditions and in the typhoon conditions, the Mitsubishi FOWT is confirmed to be the stable floater.



	Max Simulation	Min Simulation	Max Measured	Min Measured
Roll [deg]	0.76	-0.23	0.46	-0.14
Pitch [deg]	0.69	-0.26	0.41	-0.47

Fig. 8 Comparison of floater motion in 7MW operating conditions

FUTURE WORKS

There are still certain unknown facts about the dynamic effects of mooring force. In order to improve the design accuracy of mooring chains we would like to conduct the dynamic analysis in next step.

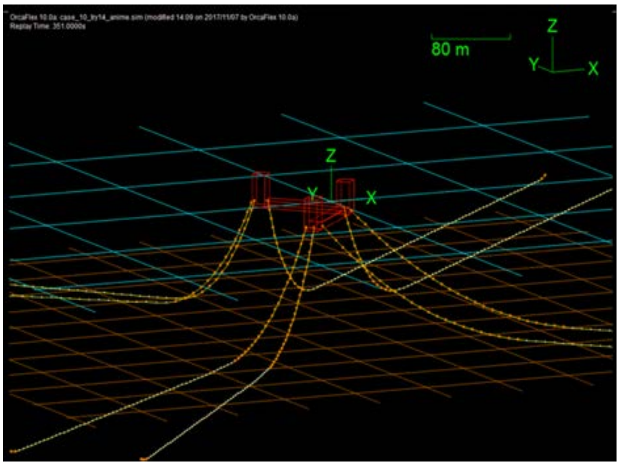


Fig. 9 Sample model of dynamic mooring analysis

CONCLUSION

In this paper, the validity of mooring design method was verified and this V-shaped semi-submersible floating structure is proved to be stable for both storm conditions are 7MW operation conditions.

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