Verification of Precision Concerning the Design of Advanced Spar Type Structure

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1. INTRODUCTION

In Japan, followed by the Great East Japan Earthquake and nuclear accident, the energy composition has been fundamentally reviewed. As a result, the demand for renewable energy is growing. Among them, the potential of offshore wind energy is very high, which is estimated at 1.6 million MW. Many kind of research has been conducted to introduce it. The government of Japan has started the experimental research project of the world's first floating offshore wind farm, which is conducted by the consortium made up of industry-academic-government organization[1]. This project is named as "Fukushima FORWARD (Fukushima Floating Offshore Wind Farm Demonstration Project)".

Concerning offshore wind energy, there are two types of platform, bottom mounted type and floating type. Since Japanese coast is topographically steep and has less area of shoal, floating type which isn't affected by water depth is more suitable. Until now, a number of concepts represented by semi-submersible type, spar type and TLP type were proposed to accomplish sufficient stability and low motion performance which is required with the floater part of floating offshore wind turbine (FOWT).

Advanced spar type is developed by JMU based on spar type[2]. This type has advantage in terms of motion performance, installation cost and ease of maintenance. Advanced spar type Floating substation was installed in 2013, and began to observe meteorological data, hydrographic data, and motion data.

In this paper, we discuss about verification of precision concerning the design of advanced type structure using observed data. We also introduce how we make use of verification data in next floating structure.

2. METHOD OF VERIFICATION

2. 1 Outline of Verification Method

We verify the design method by comparing observed value and design value concerning motion performance, mooring characteristic and structural stress. Flow of verification is shown in Fig.1.

Period of verification is set as 3 hours which is generally considered to be duration time of meteorological condition.

When we calculate design value, we use average or significant value of meteorological data. Targets for comparison are summarized in Table.1.

Concerning motion performance, Yaw motion induced by wave force is not so much big since the shape of Floating substation is almost axisymmetric shape. So, we don't include the analysis of Yaw motion.

Concerning mooring characteristic, we compare the result of the position where tension of mooring balances to the external force.

We show the definition of Fore/Aft and target positions of evaluation for structural stress in Fig.2. C1, D1, and F1 are set in the direction of aft. C2, D2, and F2 are set in the direction of starboard side.

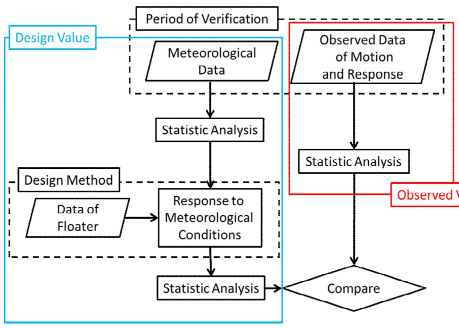

Fig.1 Flow of Verification.

Table.1 Target of Comparison.

Verification Item	Target of Comparison	External Force
Motion Performance	Surge, Sway, Heave, Roll, Pitch　[m,deg]	Wave
Mooring Characteristic	Horizontal Displacement [m]	Wave, Wind, Current
Structural Stress	Axial Stress　[MPa]	Wave

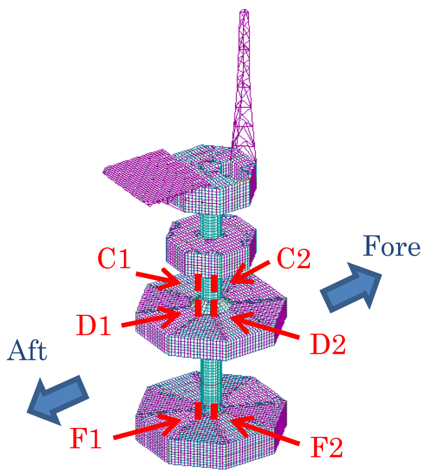

Fig.2 Model of Floating Substation.

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2. 2 Calculating Method of Design Value

(1)Acquisition of Meteorological data

Meteorological data which is used in the verification is summarized in Table.2. Each data is acquired by the devices which have been installed with Floating substation. In this verification, we don't consider the effect of floater's motion as effect of floater's motion is not considered to be large.

Concerning meteorological data, we calculate average or significant value of 3 hours for each observed data by applying statistical processing to time-series data.

Table.2 Meteorological Data.

External Force	Sensing Data	Measuring Device
Wind	Velocity, Direction	Supersonic Anemometer
Wave	Height, Period, Direction	Directional Wave Meter
Current	Velocity, Direction	Directional Wave Meter

(2)Calculating the Response to Meteorological Condition

Methods of analyzing each response to meteorological condition are indicated below.

①Motion Performance

By inputting significant values calculated in (1) to the response function which was calculated by the three dimensional sink-source method program, we conduct short-term prediction. We assume Bretschneider-Mitsuyasu spectrum and $\cos^2\chi$ distribution as a spectrum of wave and direction distribution function respectively.

②Mooring Characteristic

We calculate external force using each average or significant value of wave, wind, and current calculated in (1). Then, we calculate the position where restoring force of mooring balances to the external force.

③Structural Stress

We calculate stress function of each position by FEM using motion function calculated in ①. By inputting each significant value calculated in (1), we conduct a short-term prediction. We assume Bretschneider-Mitsuyasu spectrum and $\cos^2\chi$ distribution as a spectrum of wave and direction distribution function respectively as same as ①.

2. 3 Calculating Method of Observed Value

Observed data of motion and response used in verification is summarized in Table.3.

Table.3 Motion and Response Data.

Target of Observation	Sensing Data	Measuring Device
Surge, Sway, Heave	Position X, Y, Z	RTK-GPS
Roll, Pitch	Rotation θ, φ	Fiber Optic Gyro (FOG)
Horizontal Displacement	Position X,Y	RTK-GPS
Axial Stress	Strain ε	Strain Gauge

Concerning observed data of motion and response, we calculate average or significant value of 3 hour for each observed data by applying statistical processing to time-series data. Methods of analyzing each data are indicated below.

①Motion Performance

By processing time-series data of position X, Y, Z, and rotation θ, φ, we calculate the standard deviation of each motion.

②Mooring Characteristic

By calculating average value of position X, Y, we calculate horizontal displacement during each period of verification.

③Structural Stress

By processing time-series data of stress which is obtained by multiplying young's modulus to strain, we calculate the standard deviation of stress for each position.

3. RESULT OF VERIFICATION

3. 1 Meteorological Condition

We selected below period as the period of verification.

Period : 0:00～3:00　1 May 2014

The analytical values of meteorological data during the period of verification are summarized in Table.4. The direction of wave, current and wind is defined according to the coordinate system in which 0 degrees conform to North of the Earth in a clockwise manner.

Table.4 Meteorological Codndition.

Wind	Average Velocity	13.2 m/s
	Average Direction	178.0 deg
Wave	Significant Wave-Height	3.9 m
	Significant Wave-Period	8.3 s
	Significant Wave-Direction	166.3 deg
Current	Average Velocity	0.2 m/s
	Average Direction	220.1 deg

When we select the period of verification, we considered below matters.

・All datum don't have a deficit.

・Meteorological conditions are relatively severe.
→It is considered that the precision of the observed data will be relatively fine, as noise of datum is suppressed if absolute values of observed data are large.

・Directions of wave, wind and current are almost constant during each period.
→It is expected to be complicated to analyze if directions change frequently during the period.

3. 2 Result of Comparison

①Motion Performance

Result of comparison between design values and observed values is shown in Fig.3. Regarding the result, design values are higher than observed values. Possible factor of this result is that wave-spectrum or direction distribute function doesn't accord.

Plausibility of wave spectrum and direction distribute function is to be verified based on detail analysis of observed data.

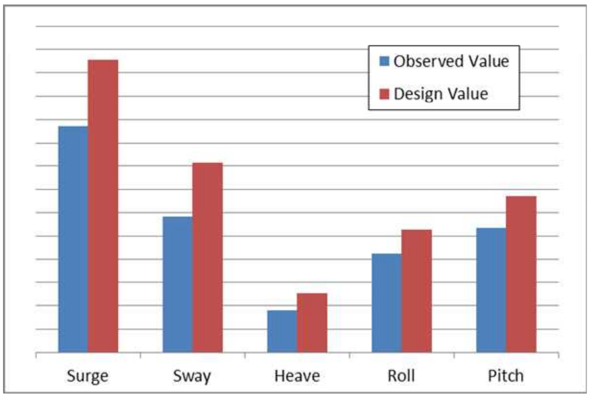

Fig.3 Result of Motion Performance.

②Mooring Characteristic

The result of comparison between design value and observed value is shown in Fig.4. This result shows average position during the period. Origin of the coordinate is defined as neutral position of the floater. Right figure shows average direction of wind, wave, and current.

The results are well accorded.

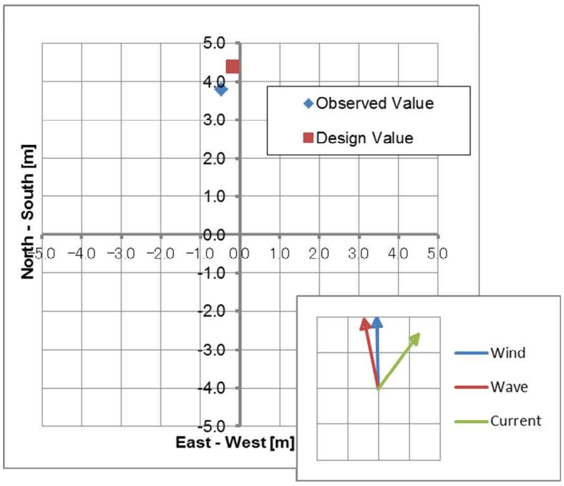

Fig.4 Result of Tensile Force of Mooring.

③Structural Stress

Result of comparison between design values and observed values is shown in Fig.5. Order of the result is almost same as we assumed. One of the possible factors of error is that wave-spectrum or direction distribute function doesn't accord. Another factor is that observed value is the result of surface, despite design value is the result of neutral axis. We have to consider local bending stress to conduct more precise evaluation.

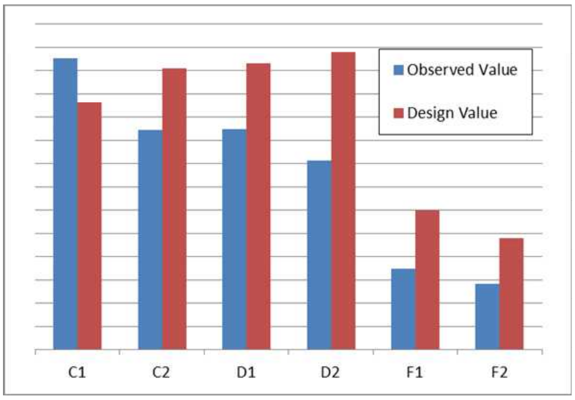

Fig.5 Result of Structural Stress.

4. MAKE USE OF VERIFICATION DATA IN NEXT FLOATING STRUCTURE

As second phase of the project, construction of two large FOWT is planned. JMU is in charge of constructing floater part of one (We call it as 2nd floater). As 2nd floater is to be installed large wind turbine, sufficient stability and low motion performance are required as same as Floating substation. And the dock where we can construct is limited. So, we decided adopting advanced spar type to 2nd floater.

We used the knowledge about motion performance which was acquired through the previous described verification to decide principle particulars of the floater. The shape and principle particulars of 2nd floater are shown in Fig.6 and Table.5 respectively.

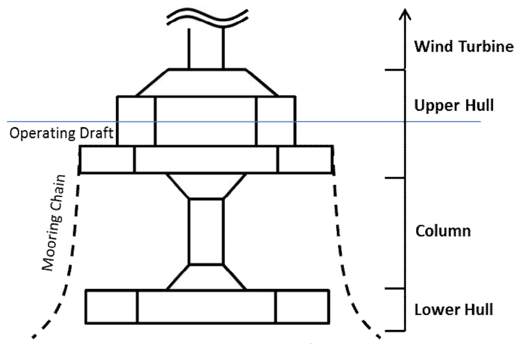

Fig.6 Shape of 2nd floater.

Table.5 Principle Particulars of 2nd floater.

Item	Value
Length	58.9 m
Breadth	51.0 m
Height (Bottom to Upper Dk.)	48.0 m
Draft (Operating)	33.0 m
Displacement	Abt. 30,000 ton

One of the different things from Floating substation is that 2nd floater has a big upper hull. The role of it is increasing stability of the floater by enlarging area of water plane. It is also different that 2nd floater has two hulls which is under the water surface while Floating substation has 3 hulls. The purpose is improving ease of construction considering installation of wind turbine and improving motion performance. We used some kind of parameters which were obtained in the previous described verification to estimate motion performance and structural stress of 2nd floater. Concerning mooring points, we ensure ease of operation and corrosion resistance by installing them at submerged position of the floater as same as Floating substation.

2nd floater is to be installed in current year.

5. SUMMARY

We compared results of design value and observed value for motion performance, mooring characteristic, and structural stress respectively. We confirmed that results were almost coincident.

We will research about wave conditions based on the analysis of wave spectrum and direction distribution function.

ACKNOWLEDGMENT

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