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Development of floating offshore substation and wind turbine for Fukushima FORWARD

Haruki Yoshimoto
Japan Marine United Corporation

Yuji Awashima
Japan Marine United Corporation

Yuka Kitakoji
Japan Marine United Corporation

Hideyuki Suzuki
University of Tokyo, Graduate School of Frontier Science

Abstract - **This paper describes the development of “Advanced Spar Float” and introduces two pilot applications (floating power substation and floating wind turbine) for wind farm off the coast of Fukushima.**

At first, this paper describes about the concept and characteristic features of advanced spar. Advanced spar, this newly developed structure enables to suppress the motion of the float nevertheless it retains the characteristic stability that an existing spar had. And, it needs smaller area for construction than semi-submersible or the other type and can be built at once in shipyard dock. In addition, the structure is self-standing by “Lower Hull” and reduced the draft to about 50m, so the difficulties in construction and transportation that existing spar had are cleared up. For these reasons, we are sure that advanced spar can be the good solution for floating wind turbines and can realize safe and stable generation in the offshore farms with cost competitiveness.

For the example of the application, this paper also describes about the advanced spar floaters adopted in Fukushima Experimental Offshore Floating Wind Farm Project. One floater is the world’s first floating power substation. Another is the world’s largest 7MW class floating wind turbine. In the description about the application, transitions in the optimization of the shapes and dimensions of the structure are demonstrated.

I. INTRODUCTION

In recent years, a social demand for introduction of renewable energy is increasing because of rising conventional fossil energy resource and the nuclear power plant accident. For example, in the study of potential for renewable energy introduction published by Ministry of the Environment [1], Japan’s potential for introduction of renewable energy is estimated at more than 2 million MW. Among them, the potential for wind energy is about 1.9 million MW and it is over 10 times the potential for introduction of the other renewable energy sources. Furthermore, wind energy can be divided in onshore and offshore, the potential for introduction of offshore wind energy is estimated at about 1.6 million MW. In other words, 80% of the potential for introduction of renewable energy in Japan are occupied by offshore wind energy.

In offshore wind energy, there are two types of embodiment, bottom mounted type and floating type. Floating type has less relationship between cost and water depth, compared to bottom mounted type. Therefore, total project cost of floating type may be less than bottom mounted type in the case of more than about 80m water depth [2][3]. Because Japanese coast is topographically steep and has less area of shoal, floating type which can’t be affected by water depth has been attracting attention in Japan.

In other countries, countries having vast shoal area such as UK and Germany are introducing mass bottom mounted offshore wind energy. With regard to floating wind power generating systems, some floating offshore wind energy projects are conducted as demonstration tests. Hywind project [4] and WindFloat project [5] are the example of full scale demonstration tests. Hywind by Statoil is equipped with 2.3 MW wind turbine and installed at 2009 in the North Sea at a distance of 10 km off the coast of Stavanger, Norway. WindFoat by Principal Power Inc. is equipped with 2 MW wind turbine and installed at 2011 in off the coast of Portugal.

The floater part of floating offshore wind turbine (FOWT) is required sufficient stability and low motion performance. The stability performance is required as restoring force to the thrust force derived from wind turbine and low motion performance is required for the floater’s soundness in the harsh environment. These performances are often compensated each other. Until now, a number of concepts represented by semi-submersible type, spar type and TLP (Tension Leg Platform) type are proposed for accomplishing these performances [6]. Hywind is the spar type and WindFloat is semi-submersible type. As the two demonstrative projects suggest, it is thought that there isn’t the best concept adoptable to all project. The best concept will be varied by the project's environmental condition and some constraint condition. These things are same as oil and gas offshore platforms have many concepts according.

Most of FOWT concepts proposed have been diverted from oil and gas technology (i.e. semi-submersible, spar and TLP). For the oil and gas platforms, the purpose of the floater is to supply vast deck area and variable deck loads. So, the floater's concepts are optimized for these purposes. But, the purpose of FOWT is somewhat different from the purpose of oil and gas platforms. FOWT is equipped with only tower and RNA (Rotor Nacelle Assembly) while oil and gas platforms are equipped with much equipment. So, the best concept for FOWT is likely to be the newly concept which is not proposed in oil and gas platforms.

Since 2009, JMU (Japan Marine United Corporation) have been developed the newly concept named as "Advanced Spar" for FOWT which can minimize the project cost. Advanced spar concept is developed through research collaboration with the University of Tokyo and approved as AIP (Approval in Principal) by ClassNK (Nippon Kaiji Kyokai) in 2011 [7].

Meanwhile, for the reconstruction of Fukushima Prefecture severely hit by the Great East Japan Earthquake and the Fukushima nuclear power plant accident, the government of Japan started the experimental research project of the world's first floating offshore wind farm [8]. This project named as "Fukushima FORWARD (Fukushima Floating Offshore Wind Farm Demonstration Project)" is conducted by the consortium made up of Marubeni Corporation (project integrator), the University of Tokyo (technical advisor), Mitsubishi Corporation, Mitsubishi Heavy Industries, Ltd, Japan Marine United Corporation, Mitsui Engineering & Shipbuilding Co., Ltd, Nippon Steel & Sumitomo Metal Corporation, Hitachi, Ltd., Furukawa Electric Co., Ltd., Shimizu Corporation and Mizuho Information & Research Institute. And, this project has been sponsored by the Ministry of Economy, Trade and Industry since March 2012.

In Fukushima FORWARD, JMU is in charge of EPCI (Engineering, Procurement, Construction and Installation) of floater part of the floating substation and 7MW floating wind turbine. Floating substation will be installed in fiscal 2013 and FOWT will be installed after fiscal 2014.

In this paper, we describe the technical specification of advanced spar concept developed since 2009 to during Fukushima FORWARD. Then, for the example of application, we describe the design of floating substation

Fig. 1. HyWind(Left), WindFloat(Right)

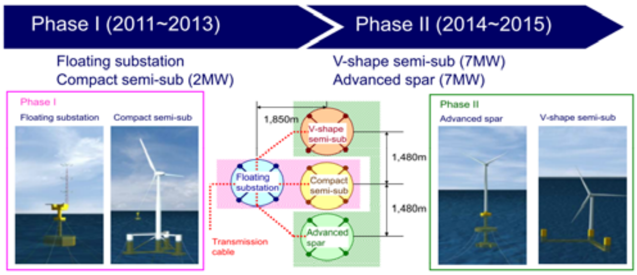

Fig. 2. Overview of Fukushima FORWARD and FOWT.

II. Advanced Spar Concept

A. General Requirements

The general requirement for FOWT is to produce more electrical power by less cost. To fulfill this requirement, the floater has to have the specification described below.

- law steel weight (displacement) and low material cost
- not so big breadth (to construct at general shipyard)
- towed in upstanding position (to simplify installation and mooring works at the offshore)
- can install big ,2MW to 10MW class, wind turbine (to achieve economies of scale)
- less heeling and less motion (to minimize the failure risk of RNA)
- less limitation to water depth and seabed property (to install the site of good wind conditions)

In addition, for the problems of the safety and environment, the floater must accomplish below things.

- not to restrict navigation of ships as possible
- minimize the impact to oceanic ecosystem
- minimize the impact to fishery industry
- high redundancy to collision damage
- less risk of drifting

Advanced spar is developed to fulfill these requirements to the maximum extent as far as possible.

Until now, there are no codes and rules standardized by an international association. But, nowadays, some classification societies publish their own guidelines[9] [10] [11] [12] and IEC is preparing international standards for FOWT as IEC61400-3-2 in TC88 [13]. Advanced spar is developed to follow the guideline published by ClassNK [9].

For the environmental conditions have to be specified in each projects, in the conceptual design stage, we don't assume the specific environmental conditions. The environmental conditions for Fukushima FORWARD are described below.

B. Overview of Advanced Spar

Advanced spar is composed of a tower, column and three hulls, and rotationally symmetric floater (Fig. 3).

Three hulls are named as "COB hull", "Middle hull" and "Lower hull" in order from top to bottom. The floater has ballast tanks in hulls and can move freely from operating draft (COB hull) to transit draft (middle hull). Mooring lines are connected to middle hull. The numbers of mooring lines are selected adequately by projects.

On lower hull, some "Motion suppression fins" are arranged

In the three hulls, there are two types of water ballast tanks, permanent ballast tanks and water ballast tanks. Permanent ballast tanks are arranged in lower hull and

Fig. 3. Advanced spar wind turbine

water ballast tanks are arranged in three each hulls.

Electric cables are derived from the bottom of lower hull and went through the cable pipe constructed as outer shell. Finally, the cables are conducted in tower at the bottom of it (not shown in Fig. 3).

Below are the characteristics of floater's performance and the detail of each part.

C. Wind Turbine

Wind turbine to be installed is assumed a horizontal axis lift type wind turbine. And, it is required to have appropriate control logic for FOWT and withstand the acceleration generated by floater's wave frequency motions. 50 years maximum horizontal acceleration will not be more than 0.5G for almost sea state, nevertheless it is depending on design environmental conditions.

The assumption of the wind turbine scale is more than 2MW class. Both upwind type and downwind type can be installed.

At the bottom of tower, tower entrance to the inside is arranged (not shown in Fig. 3). The tower entrance should be kept sufficient air gaps from water line. The working platform may be installed around the tower entrance for electric cable pull in work and RNA equipment handling.

Hub height should be decided according to the site specific wind conditions and wind turbines scale and efficiency. However, appropriate clearance between blade chips and tower entrance should be kept.

D. COB Hull

The hull located around sea water line at operating draft is called as "COB hull". "COB" is an abbreviation for "Column Outer Belt" and it was developed by IHI Corporation for the purpose of motion suppression for semi-submersible rigs.

The detailed function of COB is described in the paper [14]. The mainly hydrodynamic function of COB is to suppress heave motion in low wave frequency (Fig. 4). In addition, COB has the function to set the heave natural period to preferable frequency and keep the second order inertia moment of waterplane for stability.

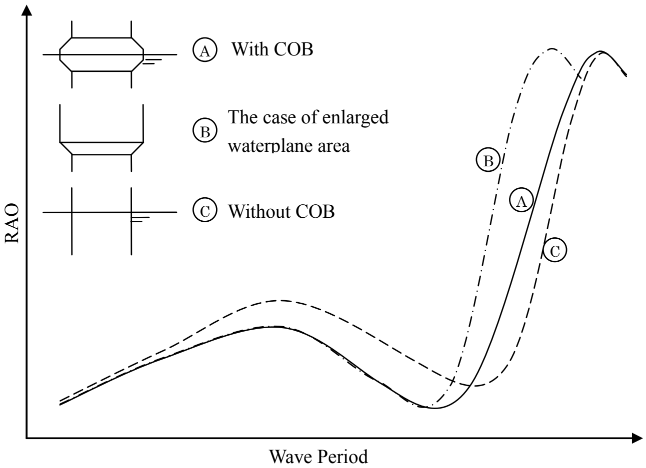

Fig. 4. Schematic curves of heave motion response

Furthermore, fenders and ladders for boarding from a support vessel are equipped on COB hull side. Internal space of COB hull is used as water ballast tanks, void spaces or the spaces for the other utility systems.

E. Middle Hull

The hull located at the middle of bottom and sea water line is called as "Middle Hull". The main purpose of the hull is to raise the center of buoyancy for keeping adequate restoring force.

Mooring lines are connected to middle hull. So as the connecting points are completely submerged in operation, mooring lines are free from harsh corrosion. In addition, it is easy to maintain and install the mooring lines on offshore because the draft of the floater can be middle hull level by ballast control and the connecting points are to be exposed to air.

In the case of upwind turbine, the turbine carries out yaw control for fronting the blade plane to the wind direction. During yaw control, RNA generates yaw torque at the top of the tower. For restoring the yaw direction of the floater, the floater has to generate sufficient yaw restoring force and damping force. It is difficult to get the forces from other than the mooring lines. By connecting the mooring lines to outer edge of middle hull, this floater generates large yaw restoring force from mooring lines.

If the mooring lines are connected at shallow point, sudden current loads can lead large overturning moment around connecting points when RNA generates thrust loads in the opposite direction to the current. But, if the mooring lines are connected to middle hull, such a large overturning moment are not generated. Internal space of middle hull is used as void spaces and water ballast tanks (Fig. 5).

F. Lower Hull

The hull located at the bottom is called as "Lower Hull". Lower hull is often filled by permanent ballast and water ballast. The main purpose of the lower hull is to lower the center of gravity. Lowering the center of gravity increases GM (metacenter height) and restoring force. In addition, heavier parts in the floater, RNA and lower hull, are set apart from each other with a distance between bottom to top, so radii of gyration is relatively enlarged. Enlarged radii of gyration makes natural period of roll and pitch longer, as a result, wave frequency pitching motions are suppressed.

Furthermore, lower hull can keep the floater in upstanding position during construction. Because the

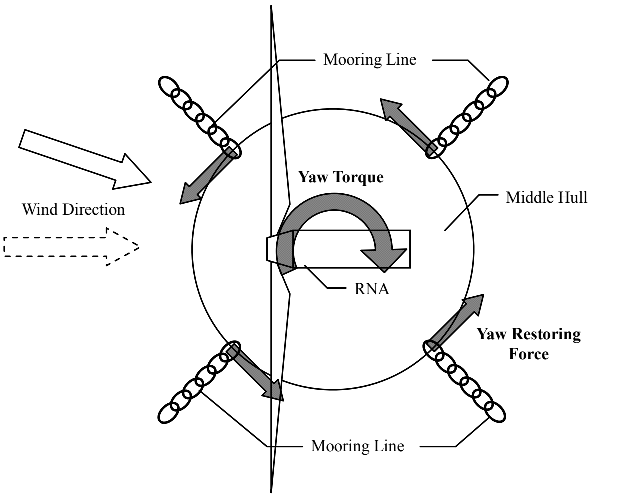

Fig. 5. Balancing of yaw torque and restoring force (Top View)

bottom of the conventional spar concept has not enough area to stand by itself, constructors have to lay the floater during construction. And they have to launch the floater, straighten up and install the wind turbine on offshore nevertheless offshore operations are dangerous and costly. In contrast, advanced spar concept allows constructor to build, launch and tow in upstanding position, and install wind turbine in dry dock. When RNA is replaced, the floater can be landed at seabed near the installation site and conducted safety working.

At the center of lower hull, a pump room for ballast pump is arranged. For locating pump room at the bottom of floater, the suction head of water ballast tanks in lower hull can be lower and it needs small capacity ballast pumps.

G. Motion Suppression Fin

Some motion suppression fins are equipped on lower hull (Fig. 6). Motion suppression fins function to suppress the motion of the float.

There are two types of damping forces expected to be generated by fins. One is the damping force to pitching motion and the other is to yawing motion. Each damping forces bring good effect not only for motion suppression but also for enlarging yaw restoring force and preventing low frequency motion. In particular, it is important to suppress low frequency motion excited by negative damping.

H. Stability

Any FOWT are required sufficient stability against overturning moments came from environmental forces (i.e. wind turbine's thrust, current load, wave drift force, etc.).

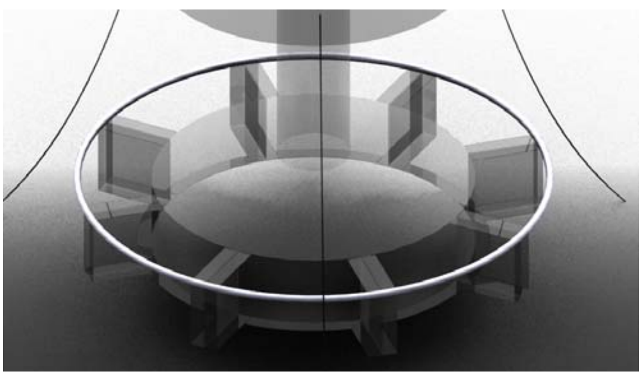
Fig. 6. Detailed image of motion suppression fin

If the size of wind turbine installed is similar, required stability is not so much different between any concepts. Restoring forces of pitching motion can be described as following equation;

$$(\text{Restoring Force}) = GM \times \Delta \times \sin\theta \tag{2.1}$$

where;
- GM: metacenter height [m]
- Δ: displacement [ton]
- θ: pitching angle [degree]

Then, GM can be described as following equation;

$$GM = KB + I/V - KG \tag{2.2}$$

where;
- KB: height of center of buoyancy from baseline [m]
- I: second order inertia moment of waterplane [m^4]
- V: displacement volume [m^3]
- KG: height of center of gravity [m]

How to get this restoring force is an important factor for studying the concept of FOWT. For example, semi-submersible type intends to increase I/V, barge type intends to increase Δ and spar type intends to increase "KB-KG".

In the case of advanced spar, the method to acquire restoring forces looks like both semi-submersible type and spar type.

First, permanent ballast filled in lower hull reduce KG and COB hull and middle hull enlarges KB. As a result, GM is increased as spar type. Also, water surface area of COB hull contributes to gain second order inertia moment (I) and increase GM as semi-submersible type.

In this way, because advanced spar can get restoring force by two means, advanced spar can keep required restoring force without enlargement of displacement.

In addition to the superiority about intact stability as described above, advanced spar has high redundancy about residual stability. In general, advanced spar keeps KB greater than KG in operating draft. Thus, nevertheless COB hull is damaged by supply boats or the other ships and inertia moments of waterplane are reduced significantly, the floater can keep high level residual stability. This floater can have big advantage in this high redundancy about stability when large scale wind farm project will be carried out.

I. Motion Performance

In addition to sufficient stability, FOWT is required to have low motion performance. The wave frequency motion

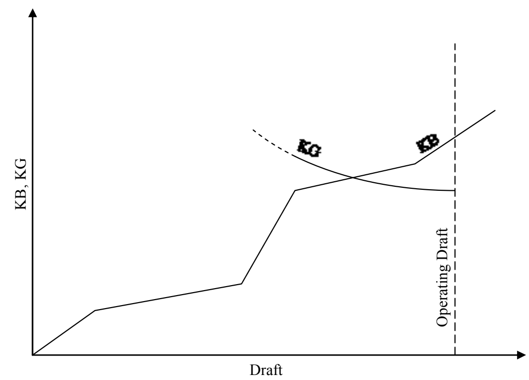

Fig. 7. Variance of KG and KB vs. Draft

of FOWT causes damage to the RNA structure and is also the main factor for determining the scantling of the tower. The impact it has on moving parts such as turbine shaft and yaw gear is high and is a factor directly linked to failure rate and equipment life.

There are three main measures to reduce the motion of FOWT.

・lengthen natural period
・increase damping force
・decrease wave exciting force

The advanced spar takes measures to increase the motion performance on all three points. Among some measures adapted to advanced spar, the outline of the characteristic measure “2 point wave free frequency” is described.

“2 point wave free frequency” is acquired by a hull form which does not get affected by the wave exciting force at two frequencies in heave mode, and is introduced in the paper [15] as an early study. Due to the hull form, the heave motion is significantly reduced (Fig. 8).

J. Instability Behavior

Furthermore, it is known that in FOWT, pitch control and floating structure motion couples, resulting in instability behavior at the same frequency as the natural period of the float [16] [17].

In motion equation, when the velocity term becomes negative, instability behavior occurs. In order to prevent instability behavior, it is suggested that adequately designing the control logic so as to reduce negative damping as much as possible is the most effective way. But, giving the float a certain level of damping force is also important.

Among the terms, radiation force and the viscosity damping force depends on the float. At the time of natural frequency of the float, compared to radiation force derived from potential flow, viscosity damping force is dominant. Therefore, the float is required to have high viscosity damping force.

To increase the viscosity damping force, it is effective to create a vortex. In the case of general commercial ships bilge keel is installed to earn viscosity damping force, and the fact that it is adopted in most of the commercial ships, it is apparent that it is an effective measure.

In the advanced spar, in the same way as the bilge keel, plate-like fins are placed in a radial fashion on top of the lower hall (refer to *G. Motion Suppression Fin*) to generate viscosity damping force. The size and number of the fin is determined through tank test and time history coupling analysis. Moreover, the motion suppression fin having being placed in a radial fashion has the function to generate yaw damping force as previously explained.

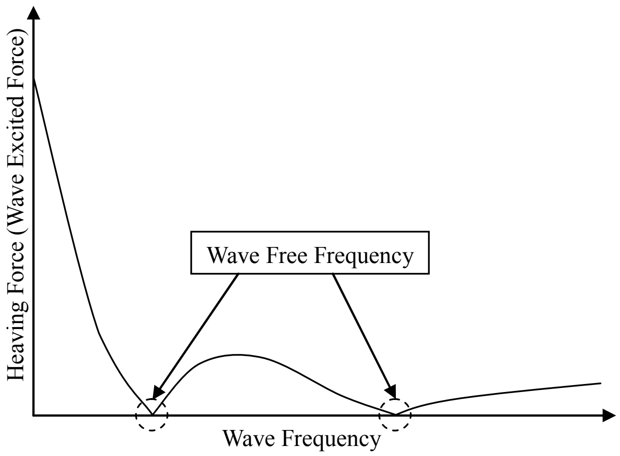

Fig. 8. 2 point wave free frequency

III. Offshore Substation of Fukushima FORWARD

From here on described is the offshore substation and 7MW FOWT of Fukushima FORWARD as an example of the application of advanced spar.

The offshore substation is a float designed to raise the voltage of the electricity generated by the offshore wind turbine and transmit the electricity to land. It is the world's first challenge to construct floating offshore electric power substation. Also equipped with instrument to observe meteorological phenomena, oceanographic phenomena, and float motion of the targeted ocean area, it also functions as an observatory obtaining data necessary for offshore wind farm.

In the electrical substation equipment part, a 25MVA transformer which raises the pressure of the 22kV electricity generated by the wind turbine to 66kV is installed. Hitachi Ltd. is responsible for the electrical substation equipment.

Moreover, underwater transmission lines are used for electrical transmission, connecting three 22kV lines and one 66kV line. Furukawa Electric Co., Ltd. is in charge of the transmission lines.

A. Environmental Conditions

The location where Fukushima FORWARD will be conducted is a sea area 20km offshore from Fukushima Prefecture where the depth of water is approximately 100-120m. The yearly average wind speed in the sea area is more than 7.5m/s at 100m above water. Tab. 1 shows the setting of meteorological and oceanographic conditions with 50 years return period. These environmental conditions have been estimated comprehensively from the following data.

・observed value from a nearby offshore platform
・wave prediction data base
・typhoon simulation
・observed value from a nearby land
・recommendation value from IEC61400-3

Table 1 Design conditions for Fukushima FORWARD
(Return period = 50 years)

Wind Velocity (10min. @Hub Height)	Abt.50m/s
Wind Velocity (10min. @10m)	41.8m/s
Turbulent Intensity (Reference)	12%
Weibull Shape Parameter	2.0
Significant Wave Height	11.7 m
Significant Wave Period	13.0 s
Current Velocity	1.5 m/s

B. Design Conditions (Construction)

The float is constructed at Yokohama Shipyard Isogo Works of JMU and needs to be towed to offshore of Fukushima. Besides the connecting of the mooring lines, as it is difficult to secure a calm sea area where we can do construction work at the sea, there is a need to complete the float inside the dock of the works. The size of the docks at Isogo Works are shown in Tab. 2 The width and length of the float needs to be smaller than the width of the dock.

In the case of general ships and offshore structures, displacement is given to the extent where there is enough to surface the float at the time of leaving the dock. Therefore, for operating in the same way as semi-submersible, there is a need to have a large displacement at the bottom of the float. However, in regard to the offshore substation which is installed at sea for a long period of time and do not expect to have periodical inspections, there is little need for it to be able to go in and out of the dock by its own buoyancy. So we assumed of lifting it out using floating cranes at the time of leaving the deck, reducing the displacement of the lower hull and the entire float.

However, as inspection and maintenance of the mooring lines are expected to take place periodically, there is a need to be able to expose the connection point of the mooring lines through ballasting.

C. Applied Rules and Regulations

In designing of the float of the substation, the following regulations were applied. Note, however that there are no crews, the classification society made significant allowances for the life saving and fire fighting criteria.

Classification Siciety: Class NK

Code and Rules:

- ClassNK Part P, Part PS
- The International Regulations for Preventing Collisions at Sea (COLREG)
- International Convention for the Prevention of Pollution from Ships (MARPOL)
- Japanese Industrial Standards (JIS)

D. Design Conditions (Motion)

The substation needs to satisfy the stability performance and low motion performance required by the electrical substation equipment and observation equipments that will be installed. In this project, performance to the same level of the floating offshore wind turbine is required.

Also, as the riser cable has a limited range that it can follow, in the same way as rigs connected with drilling risers and offshore structures for production connected with flexible risers, there is a need to design mooring lines so as it will not be pushed outside of the certain range by environmental external force.

E. External Form of the Float

From the design conditions mentioned above, we designed a float as shown in “Fig. 9”. The principal particulars are shown in “Tab. 3”.

Table 2 Size of the dock at Isogo Works

Dock Name	Size
Building Dock	325m × 45m
Repair Dock	417m × 56m
Floating Dock “Sagami”	250m × 43m
Floating Dock “Negishi”	175m × 36m

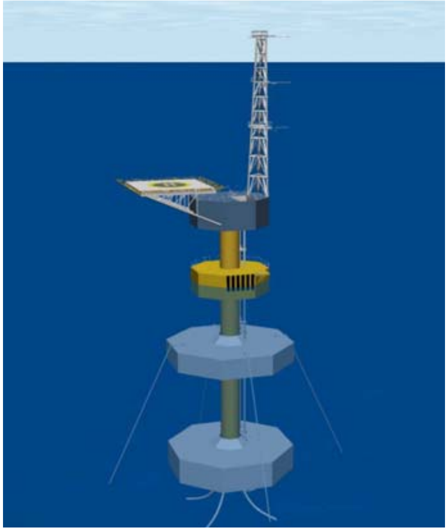

Fig. 9. Isometric view of offshore substation

Table 3 Principal Particulars of Offshore Substation

Item	Value
Length (at middle hull)	33.4 m
Breadth (at middle hull)	33.4 m
Height (bottom to tower top)	Abt. 110 m
Draft (Operating)	50.0 m
Draft (Maintenance)	32.0 m
Displacement	Abt. 13,000 ton

The electrical substation equipment is located inside the upper hull which is at the top of the hull, a tower for observing wind conditions and helicopter deck for access in case of an emergency is provided. Also assuming an operation in time of a power failure, it is equipped with an auxiliary generator. The major equipments to be installed are listed below.

Electric Substation Equipment

- 25 MVA Transformer
- 66kV GIS (Gas-Insulated Switchgear)
- 22kV Switchgear
- NGR (Neutral Grounding Resistor)

Observation Equipment

- Observation Tower
- Doppler Lidar
- FOG (Fiber-Optic Gyroscope)
- RTK (Real Time Kinematic) GPS
- Monitoring Camera
- Present Weather Sensor
- Rain Gauge
- Barometer
- Differential Temperature Meter
- Pyranometer
- GPS Compass
- Cup Anemometer and Wind Vane
- 3D Ultrasonic Anemometer
- Ultrasonic Wave Meter
- Acoustic Doppler Current Profiler
- Water Temperature Meter
- Salinity Meter
- Subsea Monitoring Camera
- Rader for Seabird
- Temperature/Humidity Meter

Marine Equipment

- Ballast Pump
- Axially Generator
- Helideck

Mooring will be done with four mooring lines. The lines are composed by chains and the nominal diameter is 132mm.

F. Maneuverability

Frequency response calculations were calculated with JMU's three dimensional sink-source method program [18]. Viscosity damping is calculated within also.

Moreover, to verify the calculation results, tank test was conducted in an experimental tank for maneuverability located at IHI Yokohama Works. The scale of the model used was approximately 1/44 and the mooring lines were moored loosely so that its tension would not impact the maneuverability.

The RAO obtained from the tank tests and RAO calculated from the three dimensional sink-source method is shown in "Fig. 10" and "Fig. 11". In either heave or pitch mode, you can see that the test and calculation results were remarkably congruent.

G. Construction

The float was constructed at JMU Yokohama Shipyard Isogo Works from December 2012 to July 2013.

To begin with, the upper hull, the COB hull, the middle hull and the lower hull were separately constructed, and were constructed by composing the hull in order. The block division and the picture of the constructed float are shown in "Fig. 12" and "Fig. 13".

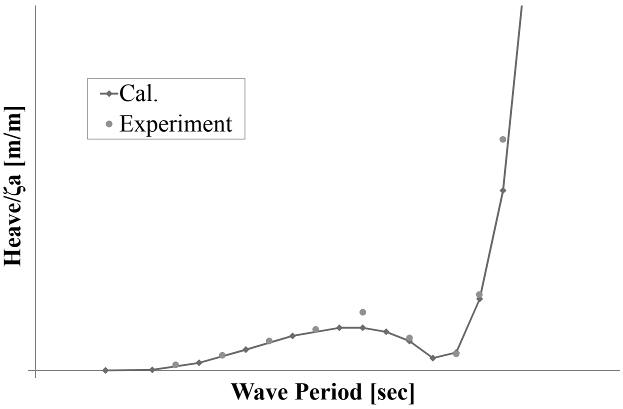

Fig. 10. Heave RAO (Cal. And Exp.)

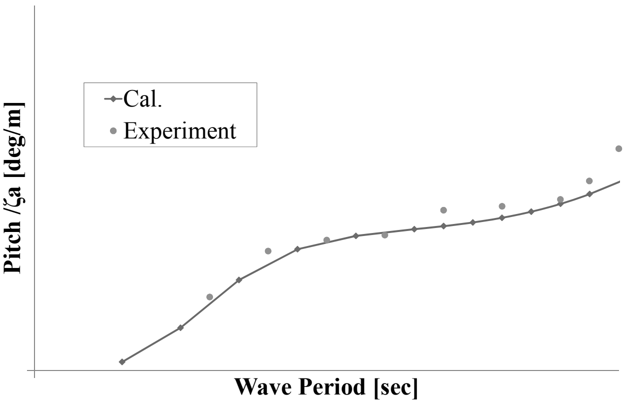

Fig. 11. Pitch RAO (Cal. And Exp.)

Fig. 12. Installation on lower hull

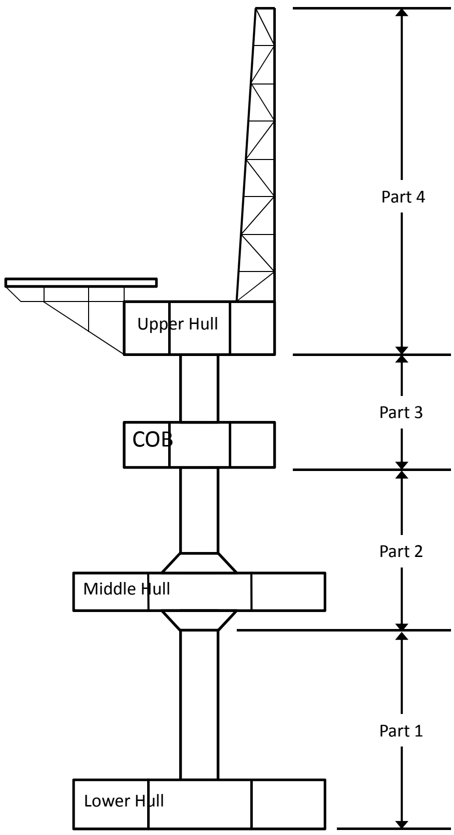

Fig. 13. Block division of offshore substation

H. Towing and Installation

Before the towing of the float, mooring lines and anchor were installed beforehand and a test to see its holding power was conducted. The holding power test was conducted by pulling together the mooring lines on the opposite side on the barge.

The towing, with the condition of towing draft (32m), was towed from Tokyo Bay going through Uraga Channel to the installation sea are in the offshore of Fukushima taking two days. The towing was done by one main tugboat and three assistant tugboats, navigating at the speed of approximately 4 knots.

At the end of July, the float was connected to the previously installed mooring lines and was installed.
We are now preparing facilities on land and in October 2013 we plan to start operation at the same time as the start of generation of the 2MW FOWT.

V. 7MW FOWT of Fukushima FORWARD

The following is about the 7MW advanced spar FOWT for the Fukushima FORWARD. As many of the environmental and design conditions are in common with that of the offshore substation as described previously, only the part that differs are explained.

A. 7MW Wind Turbine

The float will employ the advanced spar design and the wind turbine to be installed is assumed to be a 7MW wind turbine made by Mitsubishi Heavy Industries, Ltd.

This wind turbine employs a hydraulically operated train system and brush-less synchronous generator and has high reliability and durability compared to conventional wind turbines [19].

B. Principal Particulars

The principal particulars of the designed 7MW FOWT are shown in Tab. 4.

Unlike the previous advanced spars, in order to obtain enough stability, 6 upper hulls projecting greatly are installed at the water plate. This form is like COB and middle hull jointed in the substation.

Moreover, in addition to COB, by adjusting the form of the float, it is setup so the pitch frequency without waves matches the wave period that dominates in the sea area.

C. Coupling Analysis

To calculate the motion and load of the float, time history calculation using aero-hydro coupling analysis program was conducted. The program used were, UTWIND developed by Tokyo University [20] and FAST developed by NREL [21] [22].

Currently, each classification society has published guidelines for designing but in either guidelines, there is a description on the necessity of practicing time history coupling analysis in order to check the validity of the structure design [9] [10] [11] [12]. It also says to apply DLC like it is described in the IEC61400-3. Programs to calculate coupling analysis is in the midst of development around the world [23] [24]. Each program somewhat differs in the formulation and calculation conditions but the validation of the calculation results are thoroughly examined by IEC through OC3 [25] or OC4 [26], and some of the codes have gained approval from the classification society.

This time the program UTWind was used for the concept design phase and FAST was used for calculating ultimate load and fatigue load based on DLC. FAST was selected not only because it is an open source program but because it doesn't get affected by the constraints of the float form. To calculate the hydrodynamic force (additional mass, radiation force, wave exciting force) that will be input into FAST, WAMIT [27] and JMU's three dimensional sink-source method program [18] were used.

Table 4 Principal Particulars of 7MW FOWT

Item	Value
Length	Abt. 70.0 m
Breadth	Abt. 70.0 m
Height (bottom to nacelle)	Abt. 145 m
Draft (Operating)	Abt. 39.0 m
Displacement	Abt. 40,000 ton

D. Construction, Towing, Installation

Just like the offshore substation, the float for the wind turbine is expected to be constructed at JMU Yokohama Shipyard Isogo Works. The tower for the wind turbine and RNA is planned to be installed in the dock and to be towed to the installation sea area.

VI. CONCLUSION

We have developed a completely new advanced spar float as the optimal floating form for offshore floating wind generation. The characteristics of the advanced spar float are as follows.

・low motion performance
・high redundancy restoring force
・fins to gain stability

Also, we adopted the advanced spar form for an actual project of offshore substation and 7MW float, verifying its feasibility.

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