The Floating Offshore Wind Turbine with PC Floating Structure
— Hakata Bay Floating Offshore Wind Turbine —

PC 浮体構造を用いた浮体式洋上風力発電
— 博多湾浮体式海上風力発電 —


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Summary
Hakata bay floating offshore wind turbine is the world's first power generating facilities which carries the efficient wind-lens turbine. The system was developed by Kyushu University, which is a hexagonal floating structure made of concrete. The floating structure consists of six cylinder floating bodies which are connected by truss members and connecting members. The cylinder floating bodies and the truss members are made of prestressed concrete with high durability.

Structural Data
Structure: concrete hexagonal floating structure
Diagonal line length: 18.0m
Diameter of the cylinder floating body: 3.5 m
Height of the cylinder floating body: 4.0 m
Draught: 2.4 m
Client: Ministry of Environment
In charge of project: Kyushu University
Designer: Japan Port Consultants, Ltd.
Contractor: Fuji P.S Corporation
Location: Fukuoka Prefecture, Japan
Experimental period: Dec. 2011-Dec. 2012
Wind turbine: 3kW class wind-lens turbine, 2 sets
Solar panel: 1.0 kW and 0.5 kW, 2 types

1. Introduction
Wind power generation has been drawn attention as a renewable energy in Japan. Particularly, when the on land places for wind turbines are limited, the offshore wind turbine becomes promising in the country which is surrounded by the sea.
Kyushu University has tested a proof of offshore wind turbine of a float type in Hakata bay for the purpose of practical use, which used the original wind-lens[1] turbine as a core. This project name is "The actual proof experiment of Hakata bay floating offshore wind turbine". This experiment is a part of the research project of "Development of small to mid-size shrouded wind turbine with wind-lens technology" (principal inventor: Professor Yuji OHYA).
The floating offshore wind turbine is the world's first power generating facilities which carries the wind-lens turbine on the floating structure made from concrete,

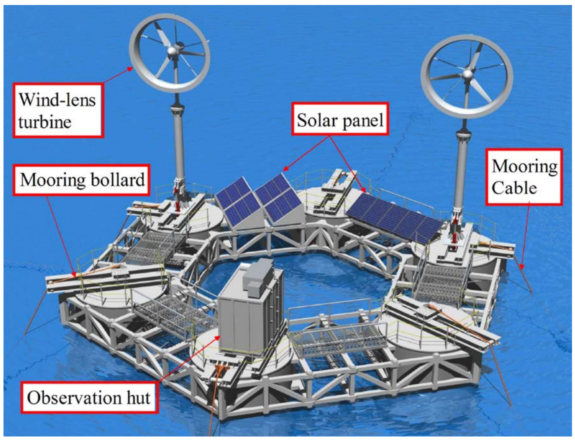

Fig. 1 Conceptional drawing

in which the cylinder floating members and the truss members are prestressed concrete with high durability.

2. Outline of the floating offshore wind turbine

The conceptional drawing of the floating offshore wind turbine is shown in **Fig. 1**. This power generating facilities carries two wind-lens turbines and two solar panels on the floating structure. The floating offshore wind turbine is fixed to six concrete anchors, which are installed in the seabed, by six mooring cables from the mooring bollards.

The setting position of the floating offshore wind turbine is about 650m away from the seashore in Hakata bay. The production of electricity, wind velocity, a wind direction, wave height, etc. were measured for one year in this experiment.

The overview of the floating structure is shown in **Fig. 2**. The floating structure consists of six cylinder floating bodies which are arranged to form a hexagon shape. The cylinder bodies are fixed by the trusses members and the connecting members.

The weight of the floating structure is about 1400 kN including wind turbines and other facilities.

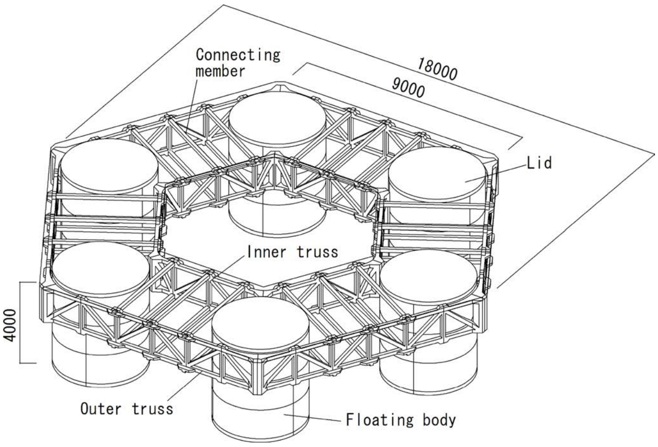

Fig. 2 Overview

Table 1 Main materials (concrete, mortar)

Item	Type	Design compressive strength	
Cylinder floating body	Side wall	Mortar	100N/mm^2
	Bottom slab	Concrete	50N/mm^2
Truss member		Concrete	50N/mm^2
Connecting member		Concrete	50N/mm^2

Table 2 Main materials (Prestressing steel)

Item		Type	Name
Cylinder floating body	Horizontal direction	Unbonded	1S17.8mm
	Vertical direction	Epoxy coated	1S12.7mm
The joint between truss members			
The joint of truss member and connecting member			
Truss member (Pre-tension)		Normal	3ϕ2.9mm

3. Design

(1) Design of the floating structure

The design condition of the floating structure is shown below.

Design wind velocity: 22 m/s (30-year return period)

Design wave height: $H_{1/3}=0.90$m, $H_{max}=1.6$m, $T_{1/3}=2.3$s (30-year return period), $_{1/3}$: One third maximum wave

Although the floating structure is made for an actual proof experiment and for the use of one year measurement, the performance requirements of the float in this experiment include:

1) Buoyancy: The floating structure shall be kept draught.

2) Stability: The floating structure shall not be capsized by storms.

3) Safety: The windmill shall not be fell by storms or the floating structure shall not be broken.

4) Durability: Steel shall not be rusted.

In order to make the system buoyant, the thickness of concrete cover was minimized. Besides, the materials with high anti-corrosion property were used to assure the high durability. The main materials of the floating structure are given in **Table 1** and **Table 2**. The floating structure used concrete, mortar, and epoxy coated prestressing steel with excellent durability.

The floating structure is complicated because it consisted of the cylinder floating bodies and the trusses. Thus, the sectional forces of the cylinder floating bodies and the trusses were computed in solid framework analysis and three-dimensional FEM analysis.

(2) Design of the cylinder floating body

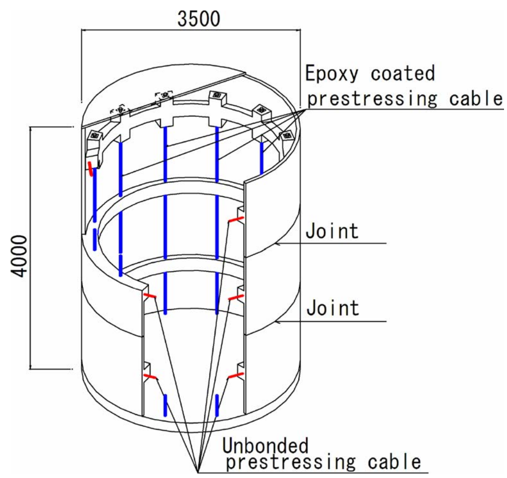

Fig. 3 Construction drawing of the cylinder floating body

Fig. 3 shows the construction drawing of the cylinder floating body. The cylinder floating body is required to keep buoyant and watertight. Therefore, the side wall thickness was designed to be 40mm. The prestressed concrete circular ribs were arranged in vertical direction. The ultra high strength mortar which was mixed with silica fume was used for the side wall of the cylinder floating bodies.

The cylinder floating body was divided into 3 segments

in the vertical direction for transportation. The segments were connected in the vertical direction by 12 epoxy coated prestressing cables (1S12.7mm). The joint of the segment was the wet joint structure, filled up with non-shrink mortar.
The thickness of the circular ribs was 200mm. One unbonded prestressing cable (1S17.8mm) was arranged in each rib. The bottom slab was RC structure which used epoxy-coated reinforcing bars.

(3) Design of the truss

The construction drawing of the trusses is shown in **Fig. 4**. The truss was fabricated in the block which consisted of an upper chord member, a lower chord member, vertical members, and a diagonal member by the pre-tension system.
The members of the truss had the cross section of 140mm wide 140mm high for weight saving. The blocks were made into the truss and linked together through a post-tension system. The post-tension was introduced in the epoxy coated prestressing cables, which were arranged in the upper chord and the lower chord.
The inner and outer trusses were linked by the connecting members with the epoxy coated prestressing cables. The connections between the blocks, the truss members and connecting member were wet joints. They were filled up with the non-shrink mortar.

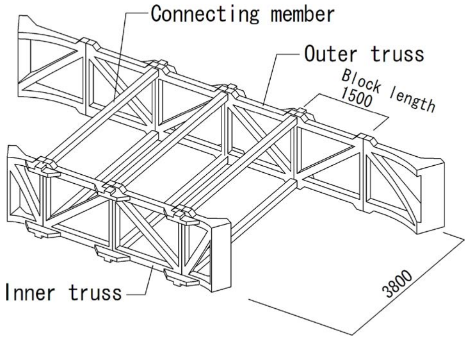

Fig. 4 Construction drawing of the truss

4. Construction of the floating offshore wind turbine

(1) Construction of the floating structure

The procedure of construction of the floating structure is detailed in **Fig. 5**.
Fig. 6 shows the construction of the cylinder floating body. Three segments of the cylinder floating bodies were installed perpendicularly on the bottom slab. Twelve epoxy coated prestressing cables, which were arranged circularly in the floating body, were prestressed with two jacks in order to connect three side wall segments and the bottom slabs.
In the next stage, the truss members were erected in the order from the inner side to outer side. The inner trusses and outer trusses were linked by the connecting members. Then, two epoxy coated prestressing cables, which were set in the connecting members, were tensioned to fix the trusses and the connecting members.
After the construction of the body was completed, the cylinder floating body was filled with styrene foam. Finally, the lid was fixed to the cylinder floating body by stainless steel bolts (M20).
The completed floating structure is shown in **Fig. 7**.

(2) Lifting, launching and towing the floating structure

Fig. 8 shows the lifting of the floating structure. The floating structure was lifted by the crane barge (lifting capacity of 310T), and was launched. The floating structure was towed by the tugboat after launching, then was moored to the shore revetment.
The floating offshore wind turbine was towed to the setting position of the Hakata bay by the tugboat after

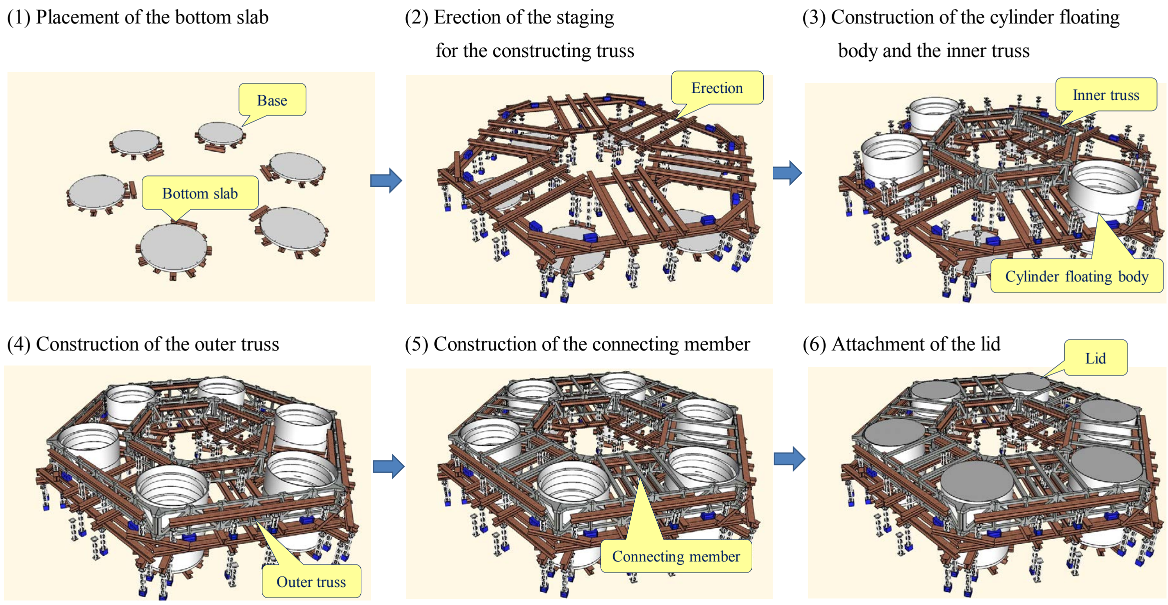

Fig. 5 Construction procedure

Fig. 6 Construction of the cylinder floating body

Fig. 7 Completion of the floating structure

the installation of the wind turbines and the facilities. Then, the floating offshore wind turbine was fixed to six concrete anchors with the mooring cables after the arrival at the setting position.

(3) Completion of the floating offshore wind turbine

Fig. 9 shows the floating offshore wind turbine in operation. The efficient wind-lens turbines are rotated by the breeze and electricity is generated smoothly. The electricity generated by the floating offshore wind turbines is stored in the storage battery inside the observation hut. It is used as electric power for the measurement apparatus or the air-conditioning equipments.

5. Conclusion

Although the actual proof experiment was ended in December, 2012, the floating offshore wind turbine is still installed in the Hakata bay up to now.

Fig. 8 Lifting of the floating structure

Fig. 9 Operation of floating offshore wind turbine

Based on this actual proof experiment, we will aim to the development of the floating composite energy-farm which set up the wind-power generation and the fish farm, etc. in the future.

This actual proof experiment was a part of research project which is commissioned by Ministry of Environment "Technology development project of 2011 global warming measures" (principal inventor: Professor Yuji OHYA).

Finally, we would like to express our thanks to Ministry of Environment, the government of Fukuoka city, Japan Port Consultants, Ltd. and the members concerning in this project. Also, we are glad that this report makes a valuable contribution to the design and construction of concrete floating body in the future.

Reference

[1] Yuji Ohya, Takashi Karasudani: A Shrouded Wind Turbine Generating High Output Power with Wind-lens Technology, Energies 2010, 3, pp. 634-649, 2010.

概　要

博多湾浮体式海上風力発電は，九州大学が独自に開発した高効率の風レンズ風車と六角形のコンクリート浮体を組み合わせた世界に例のない発電施設である。浮体は，円筒浮体 6 基をトラス部材と連結材で連結した対角線長18m の六角形構造である。

円筒浮体やトラス部材などはプレキャスト PC 構造とし，軽量化と耐久性を両立させた。特に，円筒浮体は浮力と耐久性の確保のため，シリカヒュームを混合した設計基準強度100N/㎜^{2}の超高強度モルタルを使用した。また，トラス部材は，軽量化を図るために上下弦材，鉛直材及び斜材で構成されたブロックをプレテンションン方式で一体に製作し，ブロック同士をポストテンション方式で接合する構造とした。

浮体式海上風力発電の実証試験は，当初計画から延長し，2013年11月まで継続する予定である。