

Concrete Gravity Foundation for Offshore Wind Turbine — First Demonstration of an Offshore Wind Turbine in Japan —

洋上風力発電用重力式コンクリート基礎の設計・施工 — 我が国初の洋上風力実証研究プロジェクト —



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Synopsis

Japan's first demonstration test of an offshore wind turbine was conducted in the Pacific Ocean off Choshi City, Chiba Prefecture, by the New Energy and Industrial Technology Development Organization (NEDO) and Tokyo Electric Power Company (TEPCO). In this demonstration test, a 2.4-MW offshore wind turbine (Manufactured by Mitsubishi Heavy Industry) and a Met-mast, meteorological and oceanographic observation equipment, were constructed on the rock seabed at a depth of 11 m below sea level. Concrete gravity foundations were used for these two structures. A partially prestressed concrete (PPC) structure was adopted to ensure structural safety and durability against wind and wave action and to reduce the weight of the structures for marine transport.

Structural Data

(1) Gravity foundation for 2.4-MW offshore wind turbine

Structure: Hollow-cone-type concrete gravity caisson
Dimensions: Height 22 m; Diameter 22 m (bottom slab) and 10 m (top slab).

Weight: 2,300 tons (5,300 tons after filling)

Owner: Tokyo Electric Power Company

Designers: Kobori Research Complex Inc., Kajima Corporation, Mitsubishi Heavy Industries

Contractor: Kajima Corporation

Construction period: December 2010 to January 2013

Site: Choshi City, Chiba Prefecture



Fig. 1 Offshore wind turbine and Met-mast

(2) Gravity foundation for Met-mast

Structure: Hollow-cone-type concrete gravity caisson
Dimensions: Height 15 m; Diameter 18 m (bottom slab) and 6 m (top slab).

Weight: 1,300 tons (3,500 tons after filling)

Owner: Tokyo Electric Power Company

Designers: Kobori Research Complex Inc., Kajima Corporation, and Tomoe Corporation.

Contractor: Kajima Corporation

Construction period: January 2011 to January 2013

Site: Choshi City, Chiba Prefecture

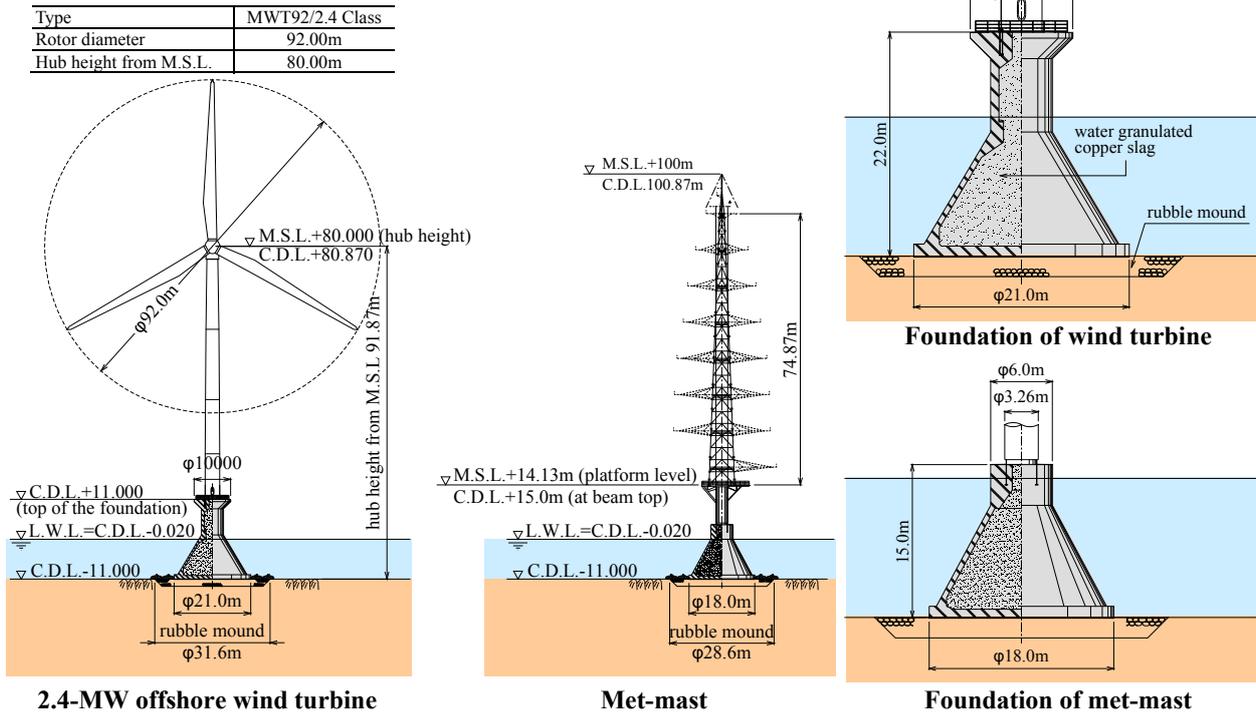


Fig. 2 Wind turbine and met-mast structures

1. Introduction

A 2.4-MW offshore wind turbine and a Met-mast were constructed in the Pacific Ocean, three kilometers off the coast of Choshi City in Chiba Prefecture in January 2013 (Fig. 1). The demonstration test of offshore wind turbine was implemented by NEDO and TEPCO. The records obtained from the demonstration test such as wind and wave conditions and the amount of electricity generated are greatly expected to contribute to the future development of offshore wind technology in Japan.

The foundations of the structures were constructed in seawater at a depth of 11 meters in the Pacific Ocean. The site is directly affected by waves during typhoons and thus is subject to severe marine conditions. Since it was considered difficult to drive piles into the rock seabed, concrete gravity foundations were selected. The foundations were hollow-coned concrete caissons that were filled after installation to increase their weight. Partially prestressed concrete (PPC) was adopted to ensure structural safety and durability against wind and wave action, and also to reduce the weight of the foundations for their marine transport. The structures of

the wind turbine and Met-mast foundations are shown in Fig. 2.

2. Design

(1) Structural Design

In the design of the foundation of the offshore wind turbine, loads such as wind forces from the turbine, seismic loads, tidal forces, wave forces and the impact of breaking wave forces should be considered. After investigating various foundation shapes, a hollow-coned foundation was adopted to reduce the wave loads and use buoyancy during transportation.

The wall of the caisson (circular shell) was made of PPC to achieve structural safety and durability. Prestressing strands were arranged helically in the inclined wall to apply vertical and horizontal prestresses and to reduce the tensile stress of the concrete. The foundation of the offshore wind turbine was to be used in a severely corrosive environment, so prestressing steel and rebar coated with epoxy resin was used. The specifications for the materials used in the wind turbine foundations are listed in Table 1.

Table 1 Specifications for offshore wind turbine materials

Concrete	Highly flowable concrete (walls and top slab) Ordinary concrete (bottom slab)	
Design strength	40 N/mm ²	
Reinforcing bars	SD345 (epoxy resin coated)	
Prestressing steel	Top deck	Single-strand method (pre-grouted prestressing bar: 1S17.8)
	Vertical wall	Epoxy resin-coated DYWIDAG steel bar (SBPR 930/1180, 32 diameter)
	Inclined wall	DYWIDAG strand 9S15.2MA system (epoxy resin-coated prestressing strand)

(2) Design of connection with tower

An anchor bolt system was used to connect the steel tower base of the wind turbine to the concrete foundation. Since tensile forces were considered to act in the top slab of the concrete foundation, loading tests using a 1/6th scale model and three-dimensional finite element analysis were conducted in order to verify the strength and failure characteristics of the connection and structural safety against Level 2 seismic action (Figs. 3 & 4).

The angle of rotation θ at the bottom of the tower and bending moment M at the connection are shown in Fig. 5. The maximum bending moment in the loading tests and finite element analysis was four times the design bending moment due to Level 2 seismic action. It was also verified that flexural failure, not tensile failure, occurred at the connection as a result of the concrete being reinforced using prestressing steel bars.



Fig. 3 Loading tests at the connection

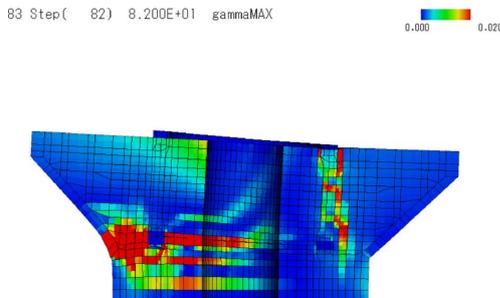


Fig. 4 Strain distribution by finite element analysis

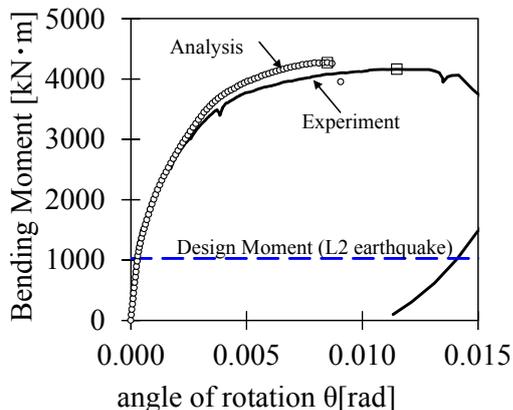


Fig. 5 M - θ at tower bottom connection

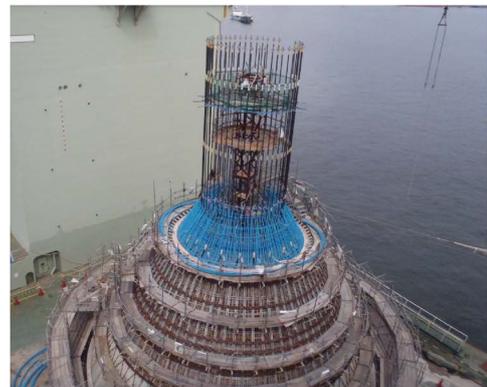
3. Construction

(1) Development of caissons

Concrete caissons were designed to be produced on a floating dock and then loaded onto a floating crane using buoyancy. A floating dock was moored at Kashima Port, Ibaraki Prefecture near Choshi City and the production of caissons started in December 2010. However, the quay in Kashima Port was damaged by the earthquake on March 11, 2011, whereupon the caisson production yard had to be moved to Higashi-harima Port in Hyogo Prefecture to continue production. The arrangement of the prestressing steel strands and bars in the caissons is shown in Fig. 6. Completed caissons are shown in Fig. 7. The completed caissons were loaded again onto the floating dock and transported back to Kashima Port.



Inclined wall



Vertical wall

Fig. 6 Arrangement of prestressing steel bars



Fig. 7 Completed caissons

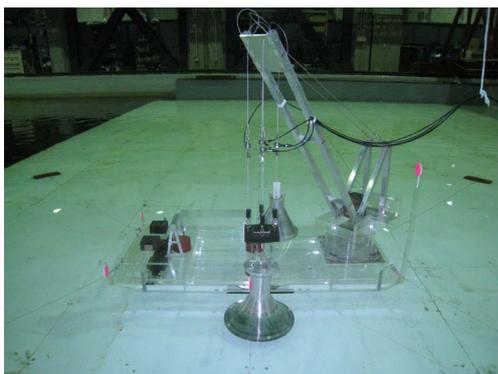


Fig. 8 Hydraulic testing



Fig. 9 Installation of caissons

(2) Installation of caissons

The caissons were installed using a 1,600-ton floating crane. The concrete foundation of the offshore wind turbine weighed 2,400 tons and could not be lifted using the floating crane. Buoyancy was therefore used for lifting. Since the construction site faces the Pacific Ocean, it was predicted that the floating crane would be oscillated by long-period waves and the lifted caissons would swing considerably. Thus, the oscillation of the caisson during installation using the floating crane was verified by hydraulic testing (Fig. 8), and a method was adopted to lift the caisson onto the side of the hull of the floating crane to reduce the swinging of the caisson. To that end, a support frame was attached to the side of the floating crane (Fig. 9) and the caisson was lifted, transported, and installed by using its inherent buoyancy.



Fig. 10 Assembly of wind turbine using a self-elevating platform (SEP)

(3) Weighting with materials

After each caisson was installed, the hollow section was filled using a grab barge. In order to increase the stability of the caisson, water-granulated copper slag was used as the filling material (saturated unit weight: 23.0 kN/m^3).

(4) Installation of wind turbine and Met-mast

After the concrete foundations were installed, the wind turbine and Met-mast were assembled. They were secured to the caissons using bolts. A self-elevating platform, which was unaffected by wave action, was used. Assembly of the wind turbine is shown in Fig. 10.

4. Closing remarks

The foundation for an offshore wind turbine in open ocean under severe marine conditions was constructed for the first time in Japan. The March 11 (2011) earthquake occurred during the construction work, so the construction plan had to be modified and rescheduled. After a one-year delay, the wind turbine and Met-mast were successfully completed in January 2013 and power generation commenced. The design and construction experience from this project and the data derived from the power generation and wind and wave observations are expected to greatly contribute to the future development of offshore wind power technology in Japan.

概 要

(独) 新エネルギー・産業技術総合開発機構と東京電力(株)が実施する洋上風力発電等技術開発の実証研究プロジェクトとして、2013年1月に千葉県銚子市の沖合いに日本初となる本格的洋上風力発電設備と風況観測タワーが建設された。

両構造物の基礎は、水深11mの岩盤質の海底面に重力式コンクリート基礎を着底させるもので、非常に厳しい海象条件下における構造安全性と耐久性の確保、さらには海上輸送・据付等の施工性を確保するため、PC構造を用いた中空円錐型重力式ケーソンタイプとした。また、起重機船によるケーソン据付の水利実験を実施し、ケーソンの動揺を低減するために、ケーソンを起重機船の船体側面に吊り下げ、浮力を利用して設置する工法を採用した。工事途中の2011年3月11日には東日本大震災の地震の影響を受けたものの無事に完成し、実証研究が開始された。