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Safety study of a new semi-submersible offshore wind turbine

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Abstract. After the oil crisis of the 1970s, a new era of wind power began. While there is some economic value in developing wind power on some well-located land, there is another frontier where it has been found to be quite economical: offshore wind power. In the 21st century development today, more people are devoting more attention to new energy sources, of which offshore wind turbines occupy a large segment. Researchers and developers will challenge conventional power generation techniques. As the demand for energy gets higher, the fans are getting bigger and bigger, and with our design, a new type of fan has been studied, and we have studied the safety of this fan. The safety of this wind turbine was studied in three aspects, including wind load, wave load, and stability. Through the study found that this design safety and stability to meet the practical requirements, in the future application, more support surface can be added, which can effectively reduce the possibility of accidents.

Keywords: stability, wind load, wave load, floating fan, photovoltaic.

1. Introduction

In recent years, the world's demand for energy has been increasing due to the rapid development of the world economy. People's daily energy needs come mainly from coal, oil, and natural gas. However, these non-renewable fossil fuels are becoming increasingly depleted, and the burning of coal, oil, etc. also produces large amounts of carbon dioxide, sulfur dioxide, and other environmentally harmful gases. As a result, more and more experts and scientists are turning their attention to new energy sources [1]. Resource scarcity and environmental pressures are driving increased investment in new energy sectors such as wind power, photovoltaic power, solar thermal power, and biomass power. Offshore wind power is the current new growth point in the field of wind power, and some developed countries in Europe and the United States are actively developing various policy rules to encourage the development of offshore wind power [2]. Policy support is active and European offshore wind power maintains strong growth momentum. Several European countries already use the North Sea's powerful offshore wind power for domestic and production purposes; nearly 17 million kilowatts of offshore wind turbines are connected to the grid in 2021 in China; although land-based wind turbines are more common in the United States. countries, the country will become more profitable using offshore energy wind power. With the significant increase in demand for renewable energy and the rapid growth of the wind energy market, more and more energy developers are looking to the ocean to harness stronger and faster winds for cleaner energy. As offshore wind power continues to grow,

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turbine manufacturers face new challenges in their operations. In the marine environment, extreme weather and rapidly changing conditions often threaten crew safety and affect operational efficiency. To keep operations safe and avoid costly project delays, operating wind turbine manufacturers increasingly rely on accurate and specific data on key weather parameters. Just like on land, weather conditions play an important role in the operation and maintenance of offshore wind turbines. However, in contrast to onshore wind turbines, the weather is often the deciding factor in planning, building, and operating offshore wind turbines [3]. Working in unpredictable marine environments, operating offshore wind designers and operators need to collect and analyse data on everything from winds, waves, and currents to tides, lightning, and tropical cyclones. To further improve the development and utilization of offshore wind and light energy, and at the same time improve the safety of the platform, this paper will make some modifications and innovations based on the semi-submersible floating type which structure is shown in Figure 1, and adopt a new type of wind turbine as the foundation of the platform.

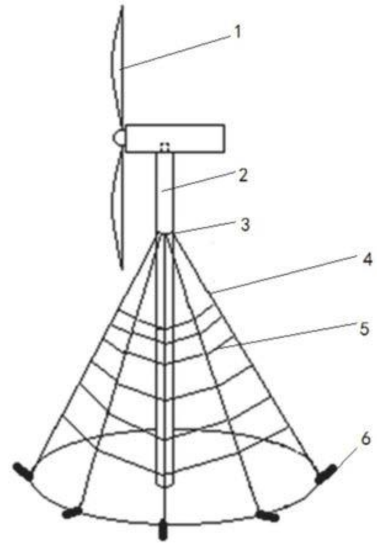

Figure 1. Platform structure.

2. Method

2.1. Research methods for wind loads on "tree triangle" semisubmersible platforms

Up to now, API, LR, Det Norske Veritas (DNV), China Classification Society(CCS), and American Bureau of Shipping(ABS) have been widely used worldwide for wind load calculation and numerical simulation, and wind tunnel experiments are also used to determine the accuracy of their data. In order to simplify the calculation model without losing accuracy, the LR specification is used to conduct wind load analysis for semi-submersible platforms.

$$F = K_W A V^2 C_S \tag{1}$$

The sign for the coefficient is K_W,where the coefficient is 0.613; V is the 1 min average wind speed at a standard height of 10m above the still water surface; C_s is the shape coefficient; A is the longitudinal wind area. All of the shape parameters are summarized in Table 1.

Table 1. Shape parameter.

Shape	Value of C_s
Spheric shape	0.40
Cylindrical	0.50
Large planar structure (hull, deck, smooth bottom deck)	1.00

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Table 1. (continued).

rig	1.25
Steel cable	1.20
Exposed beams and trusses under deck	1.30
Small components	1.40
Isolated components (cranes, suspenders, etc.)	1.50
Concentrated superstructure or similar structure	1.10

2.2. Research methods for wave loads on "tree triangle" semisubmersible platforms

2.2.1. Determination of wave theory. When entering the formal wave load calculation, we first need to determine which wave type the offshore structure is subjected to, and then conduct the formal wave load calculation using the corresponding wave calculation method. The 2010-10 specification stipulates that the following Figure 2 is used for wave pattern determination.

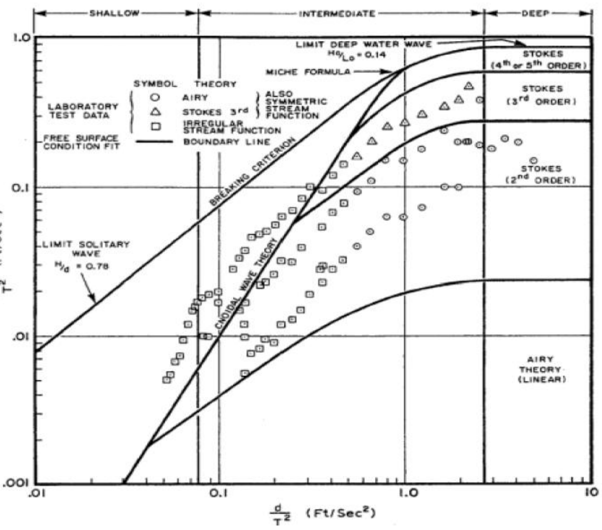

Figure 2. Ranges of validity for various wave theories and calculation [4].

2.2.2. Wave load calculation theory. Wave theory determines the fluctuations in the acceleration, velocity, and pressure fields of a fluid. The fluctuation of fluid acceleration and velocity field has a certain impact on resistance load. The fluctuation of the fluid pressure field has a certain impact on the buoyancy load. The fluid resistance load is given by the Morrison equation [5]. The applicable conditions of the Morrison force and potential flow theory are determined based on the magnitude relationship between wavelength L and D.

$$
\begin{aligned}
f_H = f_D + f_I &= \frac{1}{2} C_D \rho A u_x |u_x| + \rho V_0 \frac{du_x}{dt} + C_M \rho V_0 \frac{du_x}{dt} \\
&= \frac{1}{2} C_D \rho A u_x |u_x| + \rho V_0 \frac{du_x}{dt} + C_M \rho V_0 \frac{du_x}{dt} \qquad (2) \\
&= \frac{1}{2} C_D \rho A u_x |u_x| + C_M \rho V_0 \frac{du_x}{dt} \\
&= C_D A_D u_x |, u_x| + C_M A_I a
\end{aligned}
$$

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Where is the drag force; Is the inertial force; is the horizontal velocity of the water quality point; is the drainage volume; drag force coefficient; is the inertial force coefficient; A is the water quality point acceleration [6].

The basic idea of this formula is to divide the wave force into two linear superposition of wave forces: one is the inertial force, which is proportional to the acceleration and takes into account the impact of additional mass, and the other is the drag force, which is proportional to the square of velocity, taking into account the impact of fluid viscosity effects [7].

$$\text{CD}=\begin{cases} 0.65 & ;\Delta < 10^{-4} \\ (29 + 4 \cdot log_{10}(\Delta))/20 & ;10^{-4} < \Delta < 10^{-2} \\ 1.05 & ;\Delta > 10^{-2} \end{cases} \tag{3}$$

$$\text{CM=CA+1} \tag{4}$$

The value of is determined based on the size of the number. When <3, =1.0; When >3,

$$\text{CA}= max\begin{cases} 1.0 - 0.044(K_C - 3) \\ 0.6 - (C_{DS} - 0.65) \end{cases} \tag{5}$$

And u_x is calculated by following equations:

$$\text{ux}= \frac{\pi H_{max}}{T_{max}}\frac{coshks}{sinhkd}cos\alpha = \begin{cases} \frac{\pi H_{max}}{T_{max}}\frac{coshks}{sinhkd}cos\alpha & s \leq 35\ m \\ \frac{\pi H_{max}}{T_{max}}\frac{coshkd}{sinhkd}cos\alpha & s > 35\ m \end{cases} \tag{6}$$

$$\text{a}=\dot{u} = \frac{2\pi^2 H_{max}}{{T_{max}}^2}\frac{coshks}{sinhkd}sin\alpha = \begin{cases} \frac{2\pi^2 H_{max}}{{T_{max}}^2}\frac{coshks}{sinhkd} & s \leq 35\ m \\ \frac{2\pi^2 H_{max}}{{T_{max}}^2}\frac{coshkd}{sinhkd} & s > 35\ m \end{cases} \tag{7}$$

2.2.3. Stability research methods for "tree triangle" semisubmersible platforms. The floating fan structure mainly includes: generator unit, hub, blade tower, and floating support foundation. The generator set is connected to the blade through the hub, and the semi-submersible platform obtains a large moment of inertia in the water plane due to the relatively long distance between the columns, which has good stability [8]. The main parameters of the fan are shown in Table 2.

The transverse metacentric height GM and the longitudinal metacentric height are important indicators to measure the initial stability of a platform The larger the GM and, the greater the restoring moment MR, and the stronger the ability to resist the tilting moment. However, platforms with too large metacentrics have a short swing period, which can cause sharp swings when encountering wind and waves; On the contrary, platforms with small metacentrics have a slightly poor ability to lower the tilting torque, but they have a long swing cycle and moderate swing

When the displacement and inclination angle are constant, the magnitude of the static stability moment depends on the relative position of the center of gravity and the metacentric, that is, on the magnitude of GM. When the M point is above the G point, GM is a positive value, and the ship has a stability moment that is proportional to the GM value. When the M point is below the G point, GM is negative, and the ship has a capsizing moment that is proportional to the GM value; When point M and point G coincide, GM is zero, and the stability moment is zero [9].

GM can be used as a basic indicator to measure the initial stability of ships. In order to make the ship stable, the formula GM>0 is necessary. In this paper, the method of lowering the center of gravity below the center of buoyancy is adopted to make GM>0 to meet the stability requirements.

Table 2. Main parameters of the fan.

Object	Center of gravity z coordinate (meter)	Mass (ton)	M×z
Water pressure plate	0.03	5918.76	147.97
Buoy	3.55	2163.78	7681.42
Column	15.05	2773.03	41734.13
Triangular platform	30.06	137.67	4138.58
Circular platform	30.0	5680.44	170910.12
Photovoltaic panel	45.0	170	7664.8
Fans and towers	85.0	2092.38	178035.38

3. Result

3.1. Wind load

According to the formula in the LR specification (1). In this formula, K_W coefficient is equal to 0.613; V is the 1min average wind speed at a standard height of 10m above the still water surface; C_S is the shape coefficient, which is taken from the following table; A is the longitudinal wind area; other parameters are shown in Table 3.

Table 3. Parameters of various parts of wind loads.

Shape of each part	Windward area	Shape factor	LR load value
Blade	10832.27	1.5	1434278.54
Pylon	5183.63	0.5	228784.61
Photovoltaic panel	16666.67	1.5	2206800.04
Flat	37228.24	1	3286211.03
Expose the column	4712.39	0.5	207986.00
Photovoltaic panel support column	18943.80	1.4	2341090.45
Total wind load			9707798.83
Wind load per unit area			103.75

3.2. Wave load

In order to adapt to universality considerations, H is set as 9 m, and T is set as 12 s.The diameter of the column in this structure D is equal to 50 m, and L is equal to 227 m. After comparison, potential flow theory should be used for calculation. However, for calculation simplification considerations, the relationship between Morrison force and potential flow force is introduced here for final estimation, that is, the potential flow force is equal to twice the Morrison force. The Stokes second order wave theory is used for load calculation. The roughness coefficient k is determined based on the material properties. This structure uses new steel, and the calculated results are shown in Table 4.

Table 4. Parameters of various parts of wave load.

Character	Numerical value	Unit
Δ	1×10^{-6}	Dimensionless parameter
u_{max}	2.356	*m/s*
Re	9.0069×10^{7}	Dimensionless parameter
KC	0.5655	Dimensionless parameter
Δ	1×10^{-6}	Dimensionless parameter

Since KC is lower than 3, and according to the table of inertia coefficient and drag coefficient, C_D and C_M are 0.65 and 2.0 respectively. According to the Morrison force expression, velocity, acceleration, and area equivalents can be determined showing in Table 5.

Table 5. Parameters of various parts of wave load.

Character	Numerical value	Unit
u	$0.2906coshks\frac{d}{d+\eta}cos\alpha$	m/s
a	$0.1521coshks\frac{d}{d+\eta}sin\alpha$	m/s^2
A_I	1.963×10^6	kg/m^2
A_D	2.5×10^4	kg/m^2

Taking sinα as 1, F_{total} is 457648488 N.

3.3. Stability

At this time, the center of gravity is higher than the floating center, so the ballast is added, and the calculated center of gravity of the object after adding ballast is at 3.941 m as shown in Table 6, which is less than the height of the floating center and meets the stability requirements.

Table 6. Parameters of various parts of stability.

Character	Numerical value
Key point	21.67 m
B	12.893 m
Centre of gravity after loading	3.94 m

4. Discussion

Stability is important for offshore platforms. When subjected to external loads, the platform can rotate or flatten, which in turn affects the power generation system. When the external load changes, the platform will produce translation and rotation, which will affect the stable operation of the wind turbine [10]. Now there are many types of research on platform stability, for example, the development and experimental research of floating platform stability control system for offshore wind turbines, by combining electromechanical engineering and setting relevant sensors to make the water level in the float automatically adjust according to the external environment, and then control the center of gravity. The study and utilization of stability are not limited to the derivation of formulas in mechanics, but more practical applications are obtained through the intersection of mathematical modeling disciplines. The stability calculations used in this study are preliminary stability calculations, which are limited to small-angle stability estimates and do not consider calculations for large-inclination stability. If we want to further explore the stability of the platform, we need to draw the static stability curve of the platform, find the characteristic parameter values of the stability of the platform, and determine the static equilibrium position of the platform. Dynamic stability is then sought based on static stability. The difference between dynamic stability and static stability lies in the consideration of the angular acceleration of the platform.

The impact effect of wave forces on the platform is an important part of judging the safety of the structure. If we want to study platform safety, we have to consider the dynamic response of the structure itself, not just calculate the wave forces. For example, we can build a 3D finite element generalized model of the offshore wind turbine foundation based on the ANSYS Workbench platform, and realize the fluid-structure coupling analysis of Fluent+ANSYS APDL to analyze the static strength and dynamic response of the offshore monopile foundation and tri-pile foundation under the effect of deformation wave. The structural static strength analysis and dynamic response analysis of offshore monopile foundation and tri-pile foundation under the action of distorted waves were performed.

Based on the ANSYS Workbench platform, the generalized three-dimensional finite element models of the offshore wind turbine foundations are established, and the fluid-solid coupling analysis of Fluent+ANSYS APDL is realized, the static strength and dynamic response analyses of single-pile foundation and three-pile foundation subjected to freak wave are carried out respectively [11]. The calculation of wave forces in this study is limited to Stokes first-order waves and is based on linear wave theory for calculating wave loads. Nowadays, there are various models and methods for wave load calculation, and there are unique modelling methods and calculation methods for wave load according to different use scenarios and different wave conditions.

5. Conclusion

We have developed a semi-submersible fan that can be used for offshore navigation by adopting a modified "tree" design. The strengths and weaknesses of the fan were analyzed in a certain situation and powered the device. For the current situation of the continuous development of China's fans, this paper provides a more detailed analysis of the safety of the fan. In this paper, three perspectives are explored and their feasibility is argued. In future applications, more support surfaces can be added, which can effectively reduce the possibility of accidents. For the linkage part of this new generation of marine power equipment, lower materials, and better solutions can be used to achieve material savings and cost reduction. Regarding the prospect of wind power generation, from a world perspective, a new wave of development will occur in the marine wind power industry in the next decade for the following reasons: marine resources are very abundant and have the basis for the development of large-scale wind power generation; European support in wind power technology and policies related to it; in China, according to the "14th Five-Year "In China, according to the 14th Five-Year Plan, more than 50 GW of new wind power generation will be installed between 2022 and 2025, with Guangdong, Jiangsu, and Shandong being the largest groups. In the "double carbon" environment, the use of ocean wind power resources does not occupy land, suitable for large-scale.

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