The wind load prediction and comparative study of asymmetric semi-submersible lifting platform based on CFD

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Abstract. In order to accurately predict the wind load of asymmetric offshore structures, this paper studied the wind load of an asymmetric semi-submersible lifting platform based on the CFD software FINE/MARINE, and calculated the wind load of operation state, lifting state and survival state respectively, and compared the results with those of China Classification Society( CCS) specification. The results show that under the same wind speed, the change of wind direction angle has a great influence on the distribution of wind field around the platform. The specification calculation can not fully consider the influence of the shielding effect between the components of the superstructure, therefore, the results are larger than the numerical simulation value. In addition, the wind field distribution near the platform can be used to analyze the variation of wind load, which provides an effective method for wind load prediction and wind field analysis of asymmetric offshore structures.

1. Introduction

Semi-submersible lifting platform has been widely used in offshore lifting, submarine pipeline laying, offshore platform demolition and other aspects due to its advantages of large lifting capacity, strong ability to withstand wind and waves, and wide range of working water depth[1-2]. In the process of offshore platform design, wind load is one of the important loads to be considered. In case of severe wind conditions, wind load will seriously threaten the safety of the platform. Therefore, it is particularly important to accurately calculate the wind load of the platform. At present, there are four main methods of wind load research in the world: field measurement, wind tunnel test, numerical simulation, and the specification calculation. The field measurement is easy to be interfered by the surrounding environment, and the cost is high. Wind tunnel test, with its high reliability, is often used as an important means of wind load research[3], but the test period is long. Therefore, the research on wind load of offshore platform is still based on the specification calculation and numerical simulation. At home and abroad, many scholars have studied the wind load of offshore platforms. Boonstra H[4] calculated and compared the wind force of a semi-submersible offshore platform by two methods of specification calculation and field measurement. The results show that the field measurement value is only half of the specification calculation. Egon T D[5] found that the wind load of the test is less than...
the specification value through wind tunnel test over a semi-submersible platform. Furnes G.K[6] calculated the wind load of a drilling platform at different wind directions and compared it with the wind tunnel test data. The results are in good agreement. Lin Yi[7] studied the platform load through wind tunnel test, specification calculation and numerical simulation. He summarized that the numerical simulation value is smaller than the specification calculation value, but similar to the wind tunnel test value. Cao Mingqiang[8] justified that the reliability of the numerical simulation to calculate the wind load by using numerical calculation and model test to study the wind load of an ultra deep water drilling semi-submersible. Chen Gang[9] used wind tunnel test to study the average wind static force of the platform, and compared the calculation results with the specification calculation values. Through wind tunnel test, Zhu Hang[10] conducted the wind resistance test of HYSY-981 semi-submersible platform at the ratio of 1:100 under the steady-state gradient, and compared the results with the numerical analysis results. The results indicate that the two results are relatively consistent, and the reliability of the numerical method is explained.

In this paper, on the basis of existing research, based on the FINE / MARINE software, the wind loads of an asymmetric semi-submersible lifting platform under three states of operation, lifting and survival are numerically simulated, with the emphasis on the load size of the platform with different wind directions and the distribution of the wind field near the platform, and the calculation results are compared with the China Classification Society (CCS) specification calculation.

2. Calculation model

2.1. Model establishment

SolidWorks software is used to complete the geometric modeling of the platform. In order to improve the calculation efficiency, this paper only establishes the parts above the waterline of the platform, and simplifies or deletes the parts of the platform that have little impact on the wind load. The complete model for wind load calculation is shown in Figure 1.

![Figure 1. Three dimensional model of the semi-submersible lifting platform](image)

2.2. Computing domain and grid division

The SolidWorks model was saved as an x_t format and imported into the Hexpress software to establish the calculation domain. In order to minimize the influence of the boundary on the calculation results, the calculation domain was set as a cuboid of sufficient size. The model was placed at the bottom of the calculation domain, with the boundary 3 times of the length from the bow, 6 times of the length from the tail, 2 times of the length from both sides of the ship's side, and 3 times of the length from the bottom to the upper boundary. In order to accurately and conveniently simulate the wind
loads of the platform under different wind directions, the cylindrical domain envelope platform was built around the platform, which is defined as the calculation inner domain and the outer domain as the Boolean operation region. In order to complete the grid division of different wind direction angles, the internal domain of spin mounting calculation was adopted. Figure 2. shows the mesh division of the calculation domain and platform surface.

Figure 2. Grid division of the calculation domain and platform surface

3. Numerical simulation calculation

3.1. Governing equation
Most of the local structures of offshore platforms are blunt bodies. The numerical simulation of the surrounding flow field is similar to the flow of real air. The Reynolds time averaged Navier stocks (RANS) equation is used as the control equation of the whole flow field:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0$$  \hspace{1cm} (1)

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\mu}{\rho} \left( \frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i} \right) + S_i$$  \hspace{1cm} (2)

In the formula, i, j=1, 2, 3; Air density $\rho=1.218$Kg/m$^3$; Dynamic viscosity $\mu=1.785\times10^{-5}$Pa $\cdot$ s.

3.2. Calculation conditions and numerical calculation methods
The origin of the model coordinate system is located at the intersection of the middle longitudinal section, the middle transverse section and the waterline plane of the platform. The x-axis parallel waterline plane points to the bow, and the y-axis points to the left chord. The wind direction angle is defined as the angle between the wind direction and the positive direction of x-axis. As shown in Table 1, the wind load of the platform under the three states of operation, lifting and survival is calculated respectively, the wind direction angle is 0° to 360°, the step size is 15°, and the total wind load is 72 working conditions. Based on FINE / MARINE software, the parameters of the wind load prediction of the asymmetric semi-submersible lifting platform are set as follows: three-dimensional unsteady single-phase flow; k-omega (SST-menter) turbulence model is selected, the values of K and $\omega$ are related to the Reynolds number; the six degrees of freedom of the fixed platform, the inlet, outlet and left and right boundary velocities of the calculation domain are given, the upper boundary is set as the specified pressure condition, and the lower boundary is set as the velocity far field; The turbulence and momentum equations are discretized by AVLSMART scheme.

Table 1. Calculation condition

| Condition | Draft (m) | Wind speed (m/s) | Wind direction (°) |
|-----------|-----------|-----------------|-------------------|
| Operation | 20        | 20              | 0~360°, 15°interval |
| Lifting   | 26.4      | 10.7            |                   |
| Survival  | 17        | 28              |                   |
4. Calculation results and analysis

4.1. Expression form of calculation results
In order to facilitate the comparison between different platform draught, wind speed and other change factors, the dimensionless coefficient is adopted in this paper. The dimensionless coefficient is defined as:

(a) \( C_x = \frac{F_x}{0.5\rho V^2 A} \)  \hspace{1cm} (b) \( C_y = \frac{F_y}{0.5\rho V^2 A} \)  \hspace{1cm} (c) \( C_{Mz} = \frac{M_z}{0.5\rho V^2 AL} \)

In the formula: \( C_x, C_y, C_{Mz} \) respectively represent longitudinal wind load coefficient, the transverse wind load coefficient and yaw moment coefficient, \( F_x, F_y, M_z \) respectively represent longitudinal wind load force, transverse wind load force and yaw moment respectively; \( \rho \) is air density, take saturated moist air at 15°C, and its value is 1.218 kg / m³; \( V \) is the wind speed; \( A \) is the positive wind area of the platform; \( L \) is the total length of the platform.

4.2. Comparative analysis of loads under different wind directions
The wind load of the platform under the wind direction of 0° ~ 360° is calculated based on FINE / MARINE software. Figure 3(a) - (c) shows the comparison of the longitudinal and transverse load coefficients and the yaw moment coefficients of the platform under three conditions respectively. Some rules of the load on the platform can be summarized from Figure 3.

1) Longitudinal load coefficients \( C_x \): The longitudinal load coefficient reaches the maximum at the wind direction angle of 0° and 180°, and approaches 0 at 90° and 270°, decrease gradually from 0° to 90° and increase gradually from 90° to 180°. The change trend between 180° and 360° is basically the same as that between 0° and 180°.

2) Transverse load coefficients \( C_y \): The transverse load coefficients is close to 0 when the wind direction angle is 0° and 180° and approaches the biggest when the wind direction angle is 90° and 270°, it increases gradually from 0° to 90° and decreases gradually from 90° to 180°. The change trend between 180° and 360° is basically the same as that between 0° and 180°.

3) Yaw moment coefficients \( C_{Mz} \): The peak value of yaw moment coefficient appears near 30°, 120°, 195° and 345° respectively. It is found that the moment coefficients at 345° is the largest.

4.3. Comparative analysis of CFD calculation and CCS specification calculation
Figure 4 shows the comparison between the CFD calculation value of wind load and the CCS specification calculation value under three conditions of the platform, from which we can see:

1) The results of CCS and CFD numerical simulation have the same trend with the wind direction angle. The results of CCS and CFD numerical simulation basically show symmetrical distribution with the wind direction angle, and the numerical simulation can reflect the subtle differences of each angle.

2) The results of CCS are larger than those of the numerical simulation, which shows that the specification calculation method can not fully consider the influence of the front and back shielding effect between the components of the superstructure.
3) The wind load is closely related to the platform draft. Among the three states, the survival state has the largest load, the second is the operation state, and the smallest is the lifting state.

4.4. Detailed analysis of wind field
Taking the wind direction angle of 180° as an example, Figure 5 shows the flow field distribution near the platform surface. The flow field near the platform surface reflects the characteristics of velocity, vortex and circumfluence. It can be seen from Figure 5 that vortices and backflows are very easy to occur at platform corners and between structures. It can be seen from Figure 5(a) that the high pressure area is located at the windward side; from Figure 5(b) and Figure 5(c), when the fluid encounters the vertical windward side of the superstructure, the velocity will drop sharply and flow around, and at the same time, the flow back behind the superstructure will generate a relatively large vortex, as shown in Figure 5(c), which is due to the effect of air viscosity, resulting in the phenomenon of flow separation on the surface of the object, and the flow on the leeward side is caused by the low flow rate and the pressure difference caused the backflow of the fluid.

5. Results and discussion
In this paper, an asymmetric semi-submersible lifting platform is taken as the main research object. Based on FINE / MARINE software, the wind loads of platform with different wind directions are studied, and the conclusions are as follows:

1) The CCS specification calculates that the longitudinal force of the platform is the largest when the wind direction angle is 165°; the transverse force is the largest when the wind direction angle is 60°. The longitudinal force of the platform calculated by CFD is the largest when the wind direction angle is 30°; the transverse force calculated by CFD is the largest when the wind direction angle is 315°.

2) Due to the asymmetry of the platform, although the wind loads of 0°~180° and 180°~360° are basically the same, but the values are not the same.

3) The results of CCS specification and CFD numerical simulation are consistent with the wind direction. However, the influence of the front and back shielding effect between the components of superstructure can not be fully considered in the specification calculation method, so the results are larger than those of numerical simulation.

4) Due to the viscous effect of the fluid, when the air meets the vertical windward side of the superstructure, the velocity will suddenly drop and flow around, and at the same time, there will be a
relatively large vortex in the back of the superstructure.

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