Hydrodynamic characteristics of asymmetric semi-submersible lifting platform

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Abstract. The research object of this article is an asymmetric semi-submersible lifting platform, which is different from the traditional semi-submersible platform. It has an asymmetric lower hull structure. A heavy crane is installed on the right side of the platform body which is larger than the other side. Based on the three-dimensional potential flow theory, the hydrodynamic performance of the asymmetric semi-submersible lifting platform under operating conditions was studied by using the numerical calculation method of the hydrodynamic calculation software AQWA by adding viscous damping coefficients, and multiple wave angles. The RAO response amplitude operator, first- and second-order wave forces, additional mass and other hydrodynamic parameters are used to analyze the characteristics of various hydrodynamic parameters of asymmetric semi-submersible lifting platforms.

1. Introduction
With the vigorous development of the economy and the explosive increase of the population, mankind's demand for energy is increasing day by day, while the land and offshore oil and gas resources that are easy to extract have gradually been depleted and can no longer meet human needs. Therefore, the focus of energy exploration and extraction has turned to the deep ocean. As the deep sea environment conditions are complex, changeable, and extremely harsh, and marine engineering is becoming larger and more complex, offshore lifting equipment is required to have the ability to hoist large-scale and heavy-weight structures in a single operation to avoid adverse sea conditions affecting offshore engineering. Installation progress, which puts forward higher requirements for hoisting technology. To meet this demand, semi-submersible lifting platforms with large hoisting capacity and survivability in harsh sea conditions have emerged as the times require [1].

This article studies a new type of semi-submersible lifting platform, which is greatly different from the traditional semi-submersible platform structure. The new semi-submersible platform has a large and a small buoy, corresponding to two groups. The columns are also large and small, and the structure is asymmetric about the longitudinal and middle sections. Two cranes are installed on the side of the large pontoon at the same time. When the two machines are working at the same time, the distance between the lifting platform and the installed platform can be effectively and flexibly adjusted, which significantly improves the operation effectiveness.

Because the platform will generate wave-frequency wobble motion and low-frequency drift motion
under the action of harsh environmental loads, and the target object of this paper is a new type of asymmetric platform, the analysis of the hydrodynamic characteristics of the platform is of extraordinary significance. Many scholars have done a lot of researchs on the impact of various characteristics of hydrodynamics on the platform structure. Koevin Kroukovsky [2] first proposed the slice theory, and calculated the ship's surge and heave motion. Based on the classic linear slicing theory, Jensen and Peder [3] proposed a second-order theory based on the principle of perturbation, taking into account the second-order expressions of two-dimensional hydrodynamic coefficients such as the nonlinearity of wave loads, and then giving the second-order expression of the hull response. Zhang Jinping [4] reviewed the development of wave theory and wave force calculation methods for offshore platforms, and summarized the advantages and disadvantages of different wave theories and their applicable scope. Wu Lan et al. [5] established a three-dimensional hydrodynamic model for a deep-water semi-submersible platform, used AQWA software to carry out numerical simulation, studied the characteristics of hydrodynamic coefficient changes, and carried out motion response prediction.

2. Calculation model

2.1. Asymmetric semi-submersible platform ship type parameters
This article analyzes the asymmetric semi-submersible lifting platform. Taking operating conditions as an example, the relevant parameters are shown in Table 1.

| X_cog   | Y_cog | Z_cog | Kxx     | Kyy     | Kzz     |
|---------|-------|-------|---------|---------|---------|
| 60.950  | -6.556| 23.563| 32.43   | 34.26   | 40.16   |

2.2. Geometric model of asymmetric semi-submersible lifting platform
The 3D geometric model of the asymmetric semi-submersible lifting platform is completed based on Solidworks software, as shown in Figure 1. Meshing model, You can see Figure 2.
3. Viscous damping of asymmetric semi-submersible lifting platform

3.1. Calculation of the viscous damping matrix

To solve the critical damping coefficient, define the damping ratio of the system $\dot{\zeta}$:

$$\zeta = \frac{c}{2\sqrt{km}}$$  (3.1)

Where the damping ratio $\zeta$ is the ratio of the actual viscous damping coefficient $C$ to the critical damping $C_r$[4].

From this, the critical damping $C_r$ of the floating structure can be calculated:

$$C_r = 2\sqrt{(M + Ma)\times C_i}$$  (3.2)

Where: $M$ represents the structural mass or moment of inertia of the structure; $Ma$ represents the additional mass of the structure; $C_i$ represents the hydrostatic restorative stiffness of the structure.

Combining (3.1) and (3.2), among them, $m=M+Ma,k=C_i$.

For viscous damping of asymmetric semi-submersible lifting platforms, this paper takes 5% of critical damping[6]. According to formula (3.2), the viscous damping (rad/m) in three degrees of freedom for heave, roll, and pitch is calculated, as shown in Table 2.

| Degrees of freedom | Add mass (kg) | Inertial mass (kg) | Restorative stiffness (N) | Viscous damping (5%) |
|--------------------|--------------|-------------------|--------------------------|----------------------|
| Heave              | 6.878E+07    | 6.12E+10          | 1.22E+07                 | 3.94E+06             |
| Roll               | 1.427E+11    | 6.83E+10          | 2.91E+09                 | 1.49E+09             |
| Pitch              | 4.814E+11    | 9.38E+10          | 3.07E+09                 | 1.55E+09             |

3.2. Comparison of motion response of asymmetric semi-submersible lifting platform with and without added damping

Figure 3 (a)-(c) shows the comparison of motion response values with and without viscous damping in three degrees of freedom for heave, roll, and pitch.

![Figure 3](image)

(a) Heave of RAO  (b) Roll of RAO  (c) Pitch of RAO

Figure 3. RAO comparison diagram of asymmetric semi-submersible lifting platform with or without viscous damping

It can be seen from the figure that after adding viscous damping to the potential flow method, the amplitudes of the motion responses of the three degrees of freedom are significantly reduced; the viscous damping has the largest impact on the roll motion, eliminating the effect of a period of about 21s. The singularity has a maximum impact value of close to 83%; The heave motion and pitch motion also have a large impact, with the maximum impact values being about 69% and 77%, respectively. It can be known that adding viscous damping to the numerical simulation of the platform's motion can effectively suppress the resonant movement of the floating structure and eliminate singularities, so viscous damping must be considered.
4. Analysis of hydrodynamic characteristics of asymmetric semi-submersible lifting platform

4.1. Frequency domain variation characteristics of platform RAO at different wave incident angles

As shown in Figure 4, within a period of 4-60s, the RAO value of the six-degree-of-freedom motion response amplitude operator of the semi-submersible lifting platform at different wave angles under operating conditions is calculated.

It can be seen from the figure:

1. With the increase of the period, the response amplitude of the surge and sway motion of the asymmetric semi-submersible lifting platform also increases; within the range of 10-20s, the amplitude of the maximum increase in response amplitude can be seen. Outstanding low-frequency characteristics.
2. When the head wave (180°), the surge motion appears a peak around 20s. This phenomenon may be a resonance phenomenon near the natural period of the platform in the surge direction.
3. The peak of the heave motion appears around 20s. This phenomenon may be due to the natural period of the platform, which forms resonance. The amplitude of the response of the heave motion increases first with the period, reaches a peak around 20s, and then responds. The value decreases. After the period is 30s, the response amplitude approaches 1, which means that the wave follows the wave.
4. The peak of the platform's roll motion appears at about 41s, which may be the natural period of the roll, resonance occurs, and the maximum response RAO is 0.92. The phenomenon of the horizontal wave in this period should be avoided as much as possible.
5. The pitch motion has obvious wave frequency characteristics. The peak value when the wave direction angle is 180 ° appears at about 43s, which is close to the natural period of the pitch motion.
6. The yaw motion mainly occurs under the sloping waves. Due to the influence of the ship's turning moment, the maximum response RAO is about 0.29, and the amplitude decreases when the period is large.

Figure 4. RAO frequency domain curve of motion response value of asymmetric semi-submersible lifting platform.
4.2. Frequency domain variation of the first-order wave force of the platform at different wave incident angles

According to different wave incident angles, the frequency domain variation characteristics of the first-order wave force of six degrees of freedom of the platform are analyzed. $f_{wx}$, $f_{wy}$, $f_{wz}$, $M_{wx}$, $M_{wy}$, and $M_{wz}$ respectively represent the first-order wave force values of the platform in the surge, sway, heave, roll, pitch, and yaw directions. The calculation results are shown in Figure 5.

It can be seen from the figure:

1) The incident wave is incident at 180 ° (along the X direction), and the platform has obvious first-order wave forces in three degrees of freedom of surge, heave, and pitch, and the first-order wave forces in the other three degrees of freedom. Level is much smaller than these three degrees of freedom. It can be seen from the figure (a) that the maximum wave force of $9.55 \times 10^6$ N/m appears in the surge oscillation near the period of 13s, which verifies that the natural period of the platform in the surge direction is about 13s.

2) The first-order wave force of surge and sway oscillation is closely related to the incident wave angle. In the case of oblique waves, the first-order wave force in the direction of surge and sway is the wave force component of the platform, and the platform is in sway direction. The projection plane of the platform in the sway is greater than the surge direction, so the wave force in the sway direction is greater than the surge direction. At a 90-degree transverse wave, the wave force in the sway direction reaches the maximum. Due to the asymmetry of the platform's head and tail, there is a small Meas the wave force. The heave first-order wave force reached its peak in about 7s, and the maximum wave force was $2.53 \times 10^7$ N/m.

3) The first-order roll moment exhibits a low-frequency phenomenon, and under a 90 ° transverse wave, a maximum wave bending moment of $6.71 \times 10^6$ N•m appears in about 10s, and then gradually decreases. In order to maintain the stability of the platform, this period should be avoided.

4) Yaw at 7s, the bending moment of the first-order wave at 60 ° is the largest, reaching $7.67 \times 10^7$ N•m, and then it keeps decreasing and stabilizes after about 20s.

Figure 5. Frequency domain curve of first-order wave force value of asymmetric semi-submersible lifting platform.
4.3. Frequency domain variation characteristics of platform second-order wave force at different wave incident angles

The platform is to be positioned using a mooring system. The second-order wave force is the key external force affecting the mooring system. Figure 6 shows the frequency-domain variation curve of the second-order wave force of an asymmetric semi-submersible lifting platform at different wave incident angles under operating conditions.

It can be seen from the figure that the average wave drift force is mainly concentrated in 5-16s, of which the average wave drift force in the X direction is the largest at about 10s, and the average wave drift force in the Y direction decreases with the increase of the wave period. The maximum is about 7s, then it drops sharply until it is stable.

![Figure 6. Frequency domain curve of the second-order wave force value of the platform under operating conditions](image)

4.4. Frequency domain characteristics of additional mass of asymmetric semi-submersible lifting platform

The additional mass of a marine structure is a value that changes with the frequency domain, and is generally expressed in the form of a 6×6 matrix. The six values on the diagonal are those that have a greater impact on the hydrodynamic performance of the structure. The frequency-domain variation curves of six degrees of freedom additional masses are shown in Figure 7, where \( \mu_{11}, \mu_{22}, \mu_{33}, \mu_{44}, \mu_{55}, \mu_{66} \) and represent the additional mass values and moments of inertia of the platform in the surge, sway, heave, roll, pitch, and yaw directions, respectively.

It can be seen from the figure:

1. When the period is about 8s, the additional mass value in the surge direction is about 0.35 times the dead weight of the hull.
2. When the period is about 9s, the additional mass value in the sway direction is about 1.77 times the dead weight of the hull.
3. At a period of about 8.5s, the additional mass value in the heave direction is about 1.41 times the dead weight of the hull.
4. When the period is about 13s, the additional mass value in the roll direction is about 1.47 times the moment of inertia.
5. When the period is about 8s, the additional mass value in the pitch direction is about 1.39 times the moment of inertia.
6. When the period is about 8s, the additional mass value in the yaw direction is about 1.34 times the moment of inertia.
5. Conclusion
This paper uses the potential flow analysis software AQWA to numerically simulate and analyze the hydrodynamic performance of an asymmetric semi-submersible lifting platform. The following conclusions are obtained:

1. Viscous damping has a large impact on platform motion, especially in the roll and pitch directions; adding viscous damping will eliminate the singularity of the roll motion and reduce the amplitude of the movement, so viscous damping cannot be ignored.

2. The platform is asymmetric, and it is necessary to take different wave angles for more comprehensive analysis.

3. According to the calculation results of RAO, it is known that the roll motion with the period of more than 20s is the optimal state of motion; the heave motion has a greater impact on the working capacity of the semi-submersible platform.

4. The additional mass in the roll, pitch, and yaw directions is 3-4 orders of magnitude greater than the sway, surge, and heave directions.

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