The hydrodynamic response of the floating offshore photovoltaic platform foundation

Daiming Hu¹, Hao Liu¹,*, and Jie Li²

¹PowerChina Zhongnan Engineering Corporation Limited, 410019 Changsha, China
²Hunan Province Key Laboratory of Hydropower Development Key Technology, 410019 Changsha, China

Abstract. With the increasing energy and the gradual exhaustion of fossil energy, the development of sustainable energy is imminent. The land-based photovoltaic power station has become increasingly saturated in terms of space, and the photovoltaic power layout is beginning to move towards the deep sea. Therefore, the research of floating offshore photovoltaic technology has become very important. However, the research on the basic design of floating offshore photovoltaic float is still in its infancy in China. Based on three-dimensional potential flow theory and Morison equation, this paper uses finite element method to simulate the hydrodynamic response of the float foundation, and the results show that the RAO peak response of the14m floating foundation is small and the intrinsic period is large, which is the best in the design scheme. Finally, the short-term forecast is made, which provides a certain guidance for the hydrodynamic analysis of the floating offshore photovoltaic project.

1 Introduction

With the gradual depletion of fossil fuel energy, China is vigorously developing offshore photovoltaic solar power generation technology. Solar energy is a clean and renewable energy source. The vast majority of China's geographical locations are located in mid to low latitudes, with sufficient sunlight and a vast ocean area, making it very suitable for the development of floating offshore photovoltaic power generation technology, which has become very important for China's energy transformation. The optimization design and research of floating offshore photovoltaic floating foundations is urgent. At present, the hydrodynamic response analysis of floating foundation is one of the key and difficult technologies, which is widely concerned and applied in marine engineering [1-3].

To study the hydrodynamic response characteristics of floating foundations, it is first necessary to understand the theory of ocean dynamics. According to the characteristic dimensions of structures in ocean engineering applications, they are mainly divided into two types: large-sized structures and small-sized structures. The basis for its classification is related to the hydrodynamic diameter of marine structures and the wavelength of ocean waves. Usually, the ratio D/L of the hydrodynamic diameter of marine structures to the
wavelength of waves is not less than 0.2, and this type of structure is called a large-scale structure [4]. On the contrary, it is called a small-scale structure. The former usually uses three-dimensional potential flow theory to deal with the interaction between ocean structures and waves, while the latter uses the semi-empirical formula of the Morrison equation to solve.

There are currently some studies on hydrodynamic analysis of large-scale structures in China. Some researchers proposed the theory and method of underwater large-scale structures being affected by waves and conducted some experimental discussions [5]. Other researchers also analyzed the stability and motion response of large-sized structures through physical model experiments [6]. A few people discussed the radiation and diffraction problems of floating platforms using the three-dimensional potential flow theory [7]. Others discussed and analyzed the heave of six degrees of freedom motion amplitude by using the linear wave theory [8].

To increase the stability of a floating foundation, some have proposed methods such as increasing the draft depth of the floating body and the total mass of the floating platform to reduce the heave effect of waves, but this method cannot guarantee its stability. Some scholars have pointed out that a better method is to add a heave plate at the bottom of the floating foundation, which can increase the additional mass of the floating foundation, increase the natural period of the floating foundation, and make it far away from the periodic range of ocean wave energy concentration, reduce resonance phenomena, and to some extent increase viscous damping [9]. Therefore, this article designs three sets of floating foundations with different sizes of heave plates, to explore whether heave plates can reduce the heave response of floating foundation platforms. Through short-term prediction of the optimal form of heave plate structure designed in this article, a design to form a floating offshore photovoltaic floating foundation is proposed, which has good motion performance and economic benefits, thus achieving the goal of reducing costs and increasing efficiency in photovoltaic offshore engineering.

Some scholars in China have used finite element software to analyze the hydrodynamic response of barges [10-11]. But so far, there is little research on the hydrodynamic response analysis of floating offshore photovoltaic floating body foundations. Therefore, this article proposes the modeling process and calculation method for the hydrodynamic analysis of the floating offshore photovoltaic floating foundation, introduces the three-dimensional potential flow theory, Morrison equation, calculation ideas, environmental loads, modeling examples, and hydrodynamic response, and conducts short-term predictions for the floating body under extreme sea conditions.

2 Hydrodynamic modeling theory

2.1 Three-dimensional potential flow theory

For the calculation of wave forces on large-sized structures in the ocean, there are mainly three-dimensional potential flow theories. Wave forces can be obtained through Green's function, and the basic governing equation is [12]

\[ u = (u_I + u_s)e^{-iwt} \]  

\[ u_s = \frac{1}{4\pi} \iint F(r)G(x,y,z)dS \]

where \( u \) is the total velocity potential, \( u_I \) is the velocity of the incident wave, \( u_s \) is the velocity of the scattered wave, \( F(r) \) is the source intensity distribution function, \( G(x,y,z) \) is the Green function. The Green function satisfies the Laplace's equation:
\[ \nabla^2 G(x, y, z) = 0 \]  

(3)

The wave forces of large-size structures can be obtained through the incident wave velocity potential, source intensity distribution function, and Green's function.

### 2.2 Morison equation

Morison et al. (1950) proposed an effective empirical formula for solving wave forces on small-scale structures in the ocean using the equation [13]. Due to the negligible impact of small-scale structures on wave motion at high wavelengths of large waves, the wave forces acting on small-scale structures can be decomposed into resistance and inertial forces:

\[ f_H = C_m \frac{\rho D^2}{4} \frac{\partial u_x}{\partial t} + \frac{1}{2} C_d \rho D u_x |u_x| \]  

(4)

\( C_m \) is the mass coefficient, \( \rho \) is the density of seawater, \( D \) is the hydrodynamic diameter, \( \frac{\partial u_x}{\partial t} \) is the acceleration, \( C_d \) is the resistance coefficient, \( u_x \) is the velocity. There are differences in different sea areas for small-sized structures with different geometric shapes, but it can be found from relevant ocean regulations. \( C_m \) and \( C_d \) are 2.0 and 1.0, respectively.

### 2.3 Calculation process

The calculation process is mainly based on finite element software for simulation, and the calculation idea is shown in Figure 1. The first step is to establish a geometric model and mesh the model with appropriate meshes. After generating the finite element model, the fluid dynamics response was simulated. Note that the simulation of large structures is based on three-dimensional potential flow theory, while the simulation of small structures is based on the Morison equation. We generated a fluid dynamics model in the simulation by setting environmental load parameters. Finally, data processing and hydrodynamic performance analysis were conducted, and short-term predictions were made for the floating foundation based on wave spectra.

![Calculation flowchart](image)
3 Simulation example

3.1 Floating foundation model

The basic geometric parameters are shown in Table 1. Basic parameter modeling can be used to calculate the displacement, mass, center of gravity, and other parameters of the floating foundation. The corresponding finite element mesh model is generated by finite element software, as shown in Figure 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heave plate radius</td>
<td>12</td>
</tr>
<tr>
<td>Column radius</td>
<td>6</td>
</tr>
<tr>
<td>Heave plate height</td>
<td>2</td>
</tr>
<tr>
<td>Column height</td>
<td>20</td>
</tr>
<tr>
<td>Column center distance</td>
<td>100</td>
</tr>
<tr>
<td>Truss width</td>
<td>2</td>
</tr>
<tr>
<td>Truss height</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Basic parameters of floating offshore photovoltaic floating bodies.

Fig. 2. Finite element model of floating platform.

3.2 Environmental load

This section conducts a frequency domain hydrodynamic performance analysis of a floating offshore photovoltaic floating foundation using JONSWAP wave spectrum and sea conditions with a wave height of 10m as environmental loads. The sea water depth is 100m, and the calculation angle range of wave direction angle is from 0° to 90° with an interval of 15°. There are a total of 7 wave direction angles. The total period range for wave calculation is from 3s to 40s with a total of 40 wave periods.

3.3 Hydrodynamic response

By frequency domain hydrodynamic simulation calculation, the normal calculation time is about 20 minutes. Hydrodynamic analysis is conducted on the floating foundation, taking only the discussion of an example, without considering viscous damping. Since increasing the design of the heave plate can effectively reduce the co vibration effect between the floating foundation and waves, the radius of the heave plate discussed in this article is 12m, 13m, and 14m, respectively. The natural period of ocean waves is usually distributed in the
range of 3-18 seconds. Therefore, when designing an ocean floating foundation, it should be considered to avoid the overlap between the natural period of the floating foundation and the natural period of ocean waves as much as possible, to keep the floating foundation away from the ocean wave period and reduce resonance phenomena. The heave and roll RAO motion response results of the floating foundation are shown in Figure 3-5.

Fig. 3. Motion response of a 12m heave-plate.

Fig. 4. Motion response of a 13m heave-plate.

Fig. 5. Motion response of a 14m heave-plate.
From Figures 3-5, it can be seen that in the heave direction, the peak RAO is independent of the wave angle. The natural periods corresponding to the maximum RAO peaks with radii of 12m, 13m, and 14m are around 18s, 20s, and 25s, respectively. Compared to a floating foundation with a radius of 13m, the RAO peak response of a floating foundation with a radius of 14m is smaller, and the natural period is larger, which is far from the ocean wave period. So the wave has a smaller impact on its heave direction movement. In the roll direction, the RAO peak response at 0° direction is the highest, and the RAO peak response at 90° is the lowest. The natural periods corresponding to the maximum RAO peaks with radii of 12m, 13m, and 14m are around 25s, 30s, and 35s, respectively. Overall, the floating foundation with 14m is optimal among these schemes.

3.4 Short term forecasting

This article adopts the JONSWAP wave spectrum and normal sea conditions with a wave height of 5m, extreme sea conditions with a wave height of 10m as the environmental load, and the radius of the heave plate is set to 14m. Assuming a damping percentage of 5%, the motion under extreme and normal sea conditions is statistically analyzed in Table 2.

<table>
<thead>
<tr>
<th>Sea conditions</th>
<th>Surge(m)</th>
<th>Sway(m)</th>
<th>Heave(m)</th>
<th>Roll(Deg)</th>
<th>Pitch(Deg)</th>
<th>Yaw(Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.53</td>
<td>1.80</td>
<td>0.90</td>
<td>0.57</td>
<td>1.14</td>
<td>1.20</td>
</tr>
<tr>
<td>Extreme</td>
<td>4.45</td>
<td>4.77</td>
<td>3.07</td>
<td>1.14</td>
<td>1.14</td>
<td>1.49</td>
</tr>
</tbody>
</table>

From Table 2, under extreme sea conditions, the sway effect on the floating foundation is significant, and the maximum RAO motion response is predicted to reach 4.77m. Yaw also has a significant impact, with a maximum angle of 1.49 degrees. Under normal sea conditions, the heave effect on floating foundations is minimal, while the sway effect is significant. Reasonably designing the mooring system and anchoring constraints in the later stage can avoid the adverse effects of waves on the floating foundation.

4 Conclusion

On finite element software and three-dimensional potential flow theory and Morrison equation, we aimed to study the hydrodynamic response characteristics of floating offshore photovoltaic floating foundations. Through the calculation example of a pentagon floating body, the idea and modeling method of hydrodynamic calculation is proposed. This article presents the RAO motion response of floating foundations with different heave plates. Finally, short-term predictions for the floating foundation under extreme and normal sea conditions are provided. This has certain reference significance for further studying the hydrodynamic characteristics and optimization design of floating offshore photovoltaic floating foundations.

This work was supported in part by National Key R&D Program of China (No.2018YFE0208300).

References