Study on Coupling Dynamics Simulation of Floating Wave Energy Generating Platform and Tensioned Chain Lines

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Abstract. The floating wave energy power generation platform has emerged as a focal point of research in the offshore power generation sector, garnering increasing attention from scholars and researchers in the field. Due to the complex marine environment in which the floating wave energy power generation platform is located, the floating platform produces more complex structural vibration and dynamic response, which affects the platform fatigue damage and the stability of power generation to varying degrees. Therefore, it is necessary to conduct a coupled dynamics simulation study on the floating wave energy generation platform. This paper presents a novel structural design for a floating wave energy power generation platform. Utilizing the hydrodynamic simulation software AQWA, the study investigates and analyzes the coupled dynamic response of the floating platform across six degrees of freedom. In addition to this, to further minimize the load and vibrations experienced by the floating wave energy power generation platform, this paper applies four tensioned chain lines on the bottom of the platform in the vertical direction, and compared with the previous structural form. The results demonstrate that the tensioned chain line system effectively reduces the dynamic response of the floating wave energy power generation platform in all directions, especially in the direction of heave, and significantly improve the stability of the floating platform.

Keywords: Wave energy, dynamics, Floating platform, Tensioned chain lines.

1 Introduction

Wave energy is characterized by its extensive distribution, substantial reserves, and high energy density, making it a subject of increasing interest among researchers

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[1~3]. Currently, the cost of building, transporting, and installing an offshore wave energy converter (WEC) is very expensive compared to other cleanable energy sources [4]. Hence, the optimization of cost reduction and enhancement of wave energy generation stability are crucial areas for future advancement [5].

WEC can be integrated with offshore floating structures, such as floating wind turbines, to create a cohesive system known as a floating wave energy power generation platform. Currently, domestic and international scholars have extensively researched this integrated system [6, 7]. A proposal has been made for a WEC coaxial array arrangement plan that is based on an offshore floating foundation. It has been observed that this plan can offer increased restoring torque for the floating power generation platform, leading to a reduction in its pitch angle [8]. A hybrid model has been suggested for a floating platform with WEC to study the impact of WEC size, shape, and placement on power generation and platform movement [9].

In this paper, a structural form of floating wave energy power generation platform is proposed, which consists of multiple wave energy converters (WECs) and a new semi-submersible floating platform. Based on the typical ocean loading conditions, numerical simulations are carried out by using ANSYS/AQWA software to study and analyze the coupled dynamic response. And the platform and compare with that of the platform with the installation of the tensioned chain line to further improve the stability of the platform. Overall, this research can provide valuable insights for the conceptual design and stability assessment of alternative hybrid ocean energy power generation systems.

2 Fundamental Theory

2.1 Mooring system analysis theory

To guarantee the stability of platform movement, a mooring system that meets the requirements of restricted floating foundation needs to be designed. Considering the balance of computational efficiency and accuracy, this paper adopts the quasi-static method to calculate the line shape and mooring force of the mooring line, considering its distributed mass, axial stiffness, and ignoring its inertia, viscous damping, and bending stiffness. Nevertheless, the quasi-static method is still a better method to solve the dynamics of the mooring system. The structure of a single moored line is schematically shown in Fig. 1, and its force equations are shown in equation (1) and (2).

$$z_F(H_F,V_F)=\frac{H_F}{w}\left[\sqrt{1+\left(\frac{V_F}{H_F}\right)^2}-\sqrt{1+\left(\frac{V_F-wL}{H_F}\right)^2}\right]+\frac{1}{EA}\left(V_FL-\frac{wL^2}{2}\right) \tag{1}$$

$$\begin{aligned}x_F(H_F,V_F)&=L_B+\frac{H_F}{w}\ln\left[\frac{V_F}{H_F}+\sqrt{1+\left(\frac{V_F}{H_F}\right)^2}\right]+\frac{H_FL}{EA}\\&+\frac{C_Bw}{EA}\left[-L_B^2+\left(L_B-\frac{H_F}{C_Bw}\right)\mathrm{Max}\left(L_B-\frac{H_F}{C_Bw},0\right)\right]\end{aligned} \tag{2}$$

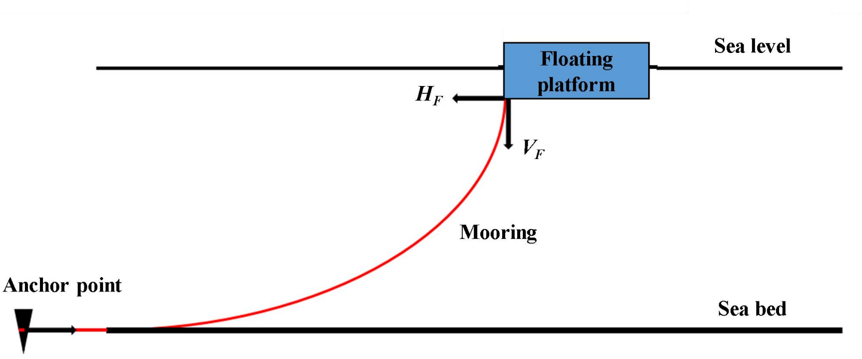


Fig. 1. Single mooring line structure

The guide hole's horizontal and vertical coordinates relative to the anchor point are denoted as x_F and z_F, while H_F and V_F represent the horizontal and vertical components of the mooring force at the Fairlead point. The weight per unit length is represented by w, L stands for the total length of the unstretched mooring line, EA represents axial stiffness, and C_B denotes the coefficient of static friction. $L_B = L - \frac{V_F}{w}$ is the length of the mooring line in seabed relaxation.

2.2 Hydrodynamic potential flow theory

Floating wave energy power generation platforms are subject to complex hydrodynamic loads in the marine environment, and to more effectively model the interaction between waves and structures, hydrodynamic load calculations should be carried out using the potential flow theory, where the force is applied to the platform reference point, and the generalized equations are expressed as shown in equation (3) to (7).

$$\vec{F}_{WRP}(x) = \vec{F}_W(x) + \vec{F}_{HS}(x) + \vec{F}_{RD}(x) + \vec{F}_{AM}(x) \tag{3}$$

$$\vec{F}_W(x) = \frac{1}{N} \sum_{k=-\frac{N}{2}-1}^{\frac{N}{2}} W[k] \sqrt{\frac{2\pi}{\Delta t} S_{\xi}^{2-sided}(\omega_0)}\, X(\omega_0, \beta)|_{\omega_0 = k\Delta\omega} e^{j\frac{2\pi kn}{N}} \tag{4}$$

$$\vec{F}_{HS}(x) = \rho g V_0 \delta_3 - C^{Hydrostatic} x_i \tag{5}$$

$$\vec{F}_{RD}(x) = -\int_0^t K(t-\tau)\dot{x}_i(\tau)\, d\tau \tag{6}$$

$$\vec{F}_{AM}(x) = -AM_R \ddot{x}_i \tag{7}$$

The total hydrodynamic load acting on the floating platform is denoted as $F_{WRP}(x)$, while $F_W(x)$ is the total excitation load of the wave. Additionally, $F_{HS}(x)$ stands for the hydrostatic pressure load, $F_{RD}(x)$ denotes the wave radiative damping load, and $F_{AM}(x)$ refers to the impulsive hydrodynamic additional mass load.

2.3 Coupled dynamics theory

To evaluate the motion response of a floating wave energy generation platform, one method involves modeling the platform as a rigid body and formulating the equation of motion as outlined in the following equation (8).

$$(M + A)x(t) + Cx(t) + Kx(t) = F_{WRP} + F_{Line} \tag{8}$$

Where M represents the mass matrix, A is the additional mass matrix, C denotes the damping coefficient matrix, and K stands for the hydrostatic restoring force matrix. F_{WRP} is the hydrodynamic load acting on the platform, F_{Line} is the mooring force.

In this study, the AQWA software was utilized for simulating and analyzing the structural dynamics of a floating wave energy platform. The main modules required for the calculation are shown in Fig. 2, including the dynamic response module, wave generation module, hydrodynamic load calculation module, and mooring force calculation module. Each module interacts with data at each time step and solves the platform dynamic response after successive iterations.

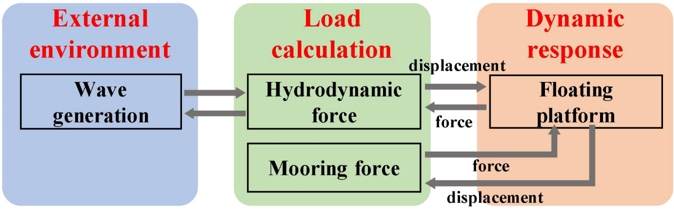
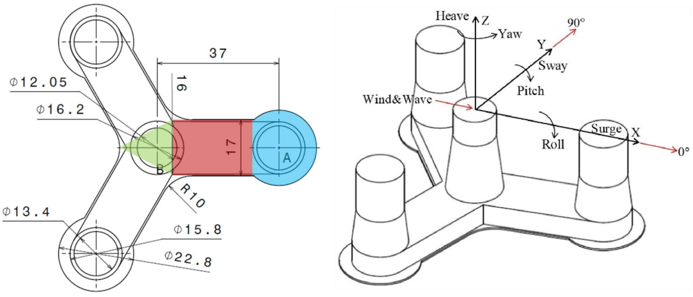


Fig. 2. Coupled dynamics module structure

3 Simulation calculation

3.1 Design of floating platform

The concept for the wave energy power generation platform presented in this paper is developed using the DTU-10MW offshore floating wind turbine as a basis, and the design of the DTU-10MW floating platform can be seen in Figure 3. The specifications for this floating platform can be found in Table 1.



(a) (b)

Fig. 3. DTU-10MW Floating Platform

Table 1. DTU-10MW floating platform performance parameters

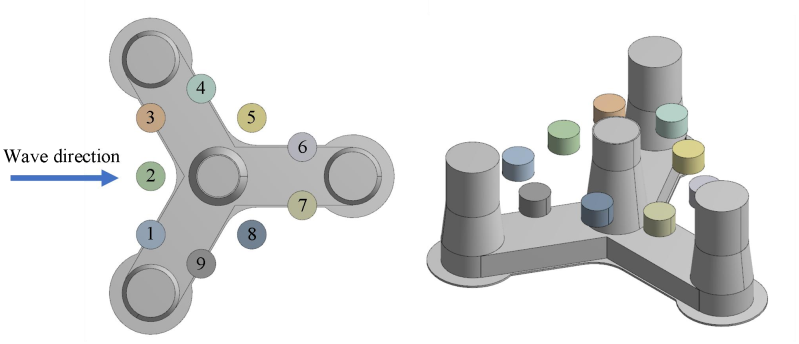
Parameter	Value
Total mass	2.1709E+07 kg
VCG from SWL	-15.255 m
VCB from SWL	-14.236 m
Draft	22 m
Freeboard	11 m
Displacement volume	2.3509E+04 kg
Roll Inertia about Centre of Gravity	9.43E+09 kg m2
Pitch Inertia about Centre of Gravity	9.43E+09 kg m2
Yaw Inertia about Centre of Gravity	1.63E+10 kg m2

3.2 Design of wave energy converters

A novel structure for generating wave energy using a floating platform is suggested in this paper, which involves the integration of nine oscillating float-type wave energy converters (WECs) with the DTU-10MW floating platform. The detail parameters of the WECs are presented in the Table 2, and their main arrangement form is shown in Fig. 4. The nine WECs are evenly arranged in arrays across the central section of the three columns on the floating platform.

Table 2. Parameters of oscillating float

Parameter	Value
Diameter	8 m
Height	5 m
Draft	3 m
VCG from SWL	1 m
Displacement volume	1.5457×105 kg
Roll Inertia about Centre of Gravity	9.79E+05 kg m2
Pitch Inertia about Centre of Gravity	9.43E+05 kg m2
Yaw Inertia about Centre of Gravity	1.24E+06 kg m2

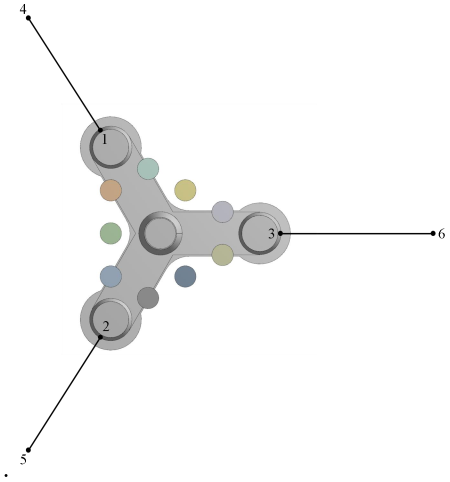


(a) (b)

Fig. 4. WECs array arrangement structure

3.3 Design of mooring and tensioned chain lines

To ensure the stability of the floating platform, it is essential to design an effective mooring arrangement and appropriate mechanical parameters, this study adopts three mooring lines center-symmetric design. The mooring layout is shown in Fig. 5, the fairlead points of the platform and the seabed anchors are detailed in the Table 3, while the performance parameters of the mooring lines are shown in Table 4.



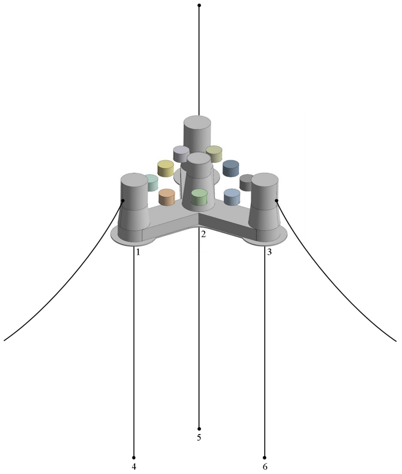


Fig. 5. Mooring line layout **Fig. 6.** tensioned chain lines arrangement

Table 3. Mooring line fairlead points and seabed anchors

Number	Fairlead point	Number	Anchor point
1	(-21.85, 37.845, 2.75)	4	(-422, 730.925, -200)
2	(-21.85, -37.845, 2.75)	5	(-422, -730.925, -200)
3	(43.7, 0, 2.75)	6	(844, 0, -200)

Table 4. Mooring line performance parameters

Parameters	Values
Diameter	76.0 mm
Mass per unit length	23.0 kg m-1
Axial Stiffness	2.33E+05 kN
Additional mass coefficient	1.0
Drag force coefficient	1.2

To minimize the dynamic response of the floating wave energy generation platform. In this study, three vertical tensioned chain lines is applied, and the structural arrangement is shown in Fig. 6. The parameters of the tensioned chain lines are consistent with those in Table 4 above, and the platform fairlead points and seabed anchor points are shown in Table 5.

Table 5. Tensioned chain line fairlead points and seabed anchors

Number	Fairlead point	Number	Anchor point
1	(-32.043, -18.5, -22)	4	(-32.043, -18.5, -200)
2	(0, 37.0, -22)	5	(0, 37.0, -200)
3	(32.043, -18.5, -22)	6	(32.043, -18.5, -200)

3.4 Design of load case

In this paper, we utilize the JONSWAP wave spectrum, grounded in irregular wave theory, to simulate sea waves. Taking into account the extreme loading conditions typical of real-world projects, we select the extreme sea state for a one-year period for our simulations. The parameters for the extreme load cases are presented in Table 6.

Table 6. Load case parameter

Parameter	Value
Wave direction	0 deg
Significant wave height	6.5 m
Wave period	0.5233 rad/s
Peak-shape parameter gamma	3.3

4 Result analysis

The simulation results are shown in Fig. 7 and Fig. 8. And Fig. 7 presents the comparison of displacements in the three translational directions: surge, sway, and heave. Meanwhile, Fig. 8 displays the comparison of angular movements in the three rotational directions: roll, pitch, and yaw.

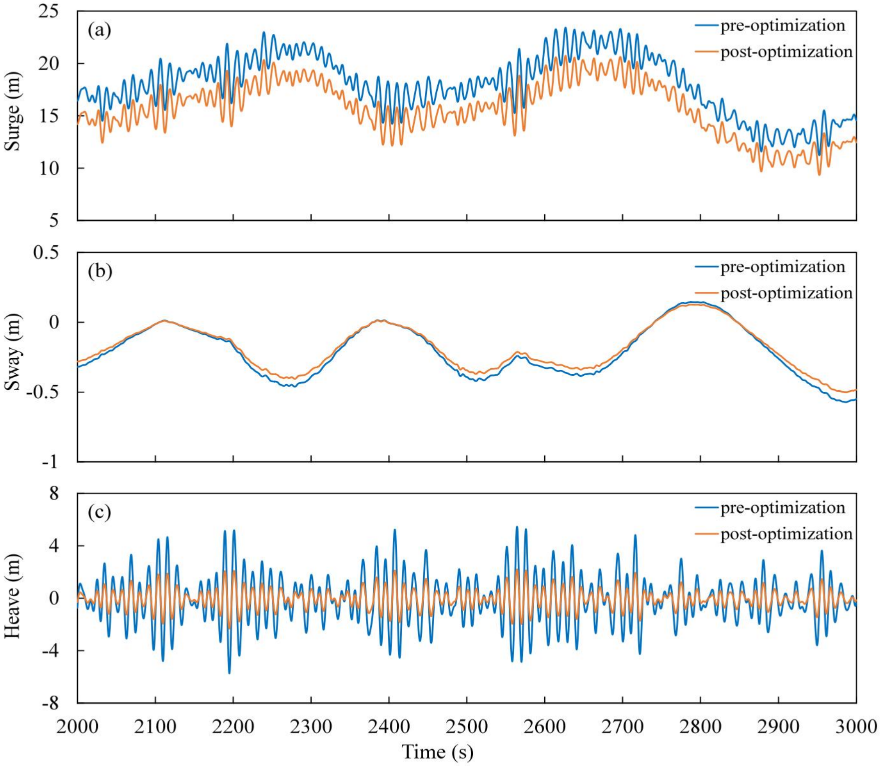


Fig. 7. Displacement of floating platform in surge, sway, and heave direction

As can be seen from (a) and (c) in Fig. 7, after applying the tensioned chain line, the displacement of the platform in the surge and heave directions shows a significant reduction, particularly in the heave direction, where the reduction ratio approaches 50%. In the sway direction, as depicted in Fig. 7 (b), the displacement of the platform before and after optimization remains largely unchanged. This is primarily because the wave load acts in a direction that is not the predominant direction of sway, resulting in minimal impact on the dynamic response of the platform in this direction.

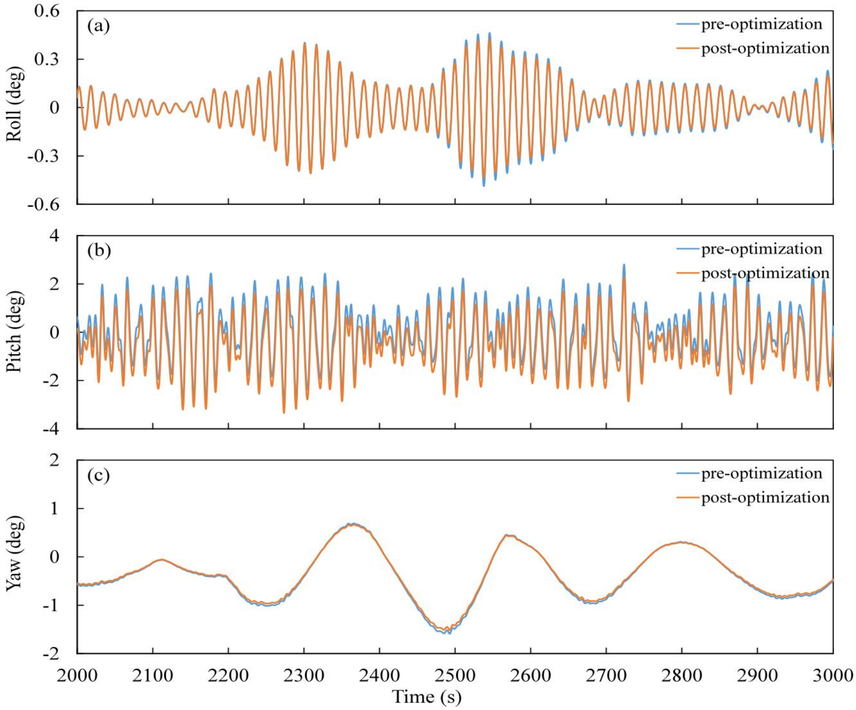


Fig. 8. Angle of floating platform in roll, pitch, and yaw direction

From Fig. 8, it can be seen that the stability of the floating platform in the direction of the three rotational degrees of roll, picth, and yaw, is not significantly affected by the application of the tensioned chain lines. The most significant impact is in the pitch direction, as shown in Fig. 8(b), which can lower the rotation angle of the floating platform by about 5%. The main reason is that when the platform is rotating, the tensioned chain line pull force will produce a restoring moment on the center of the floating platform, limiting the rotation of the floating platform.

5 Conclusion

This study presents a new structure of floating wave energy generating platform, building on the structural design of the DTU-10MW offshore floating wind turbine platform that integrates wave energy converters. The dynamic response analysis of this structure is conducted using ANSYS/AQWA. Additionally, to minimize the amplitude of the platform's motion, an optimization model incorporating a tensioned chain line is developed, and the six-degree-of-freedom dynamic response results are compared between the pre-optimization and the optimization. The simulation results show that the tensioned chain line has minimal impact on the motion of the floating platform in the sway, roll, and yaw directions. However, it does affect the platform's motion in the surge, heave, and pitch directions, with a notable reduction in the maximum heave motion by approximately 50%. In conclusion, the optimization model of the tensioned chain line proposed in this paper significantly enhances the platform's stability in the heave direction, providing a valuable foundation for future study.

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