Numerical Simulation of Main Structure of Full-Submersible Deep-Sea Aquaculture Platform Under Action of Water Waves

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Abstract: The development and utilization of marine resources by human beings is gradually moving towards the deep sea, and deep-sea aquaculture platforms have emerged to meet the needs of aquaculture and food security. To better understand the motion response characteristics of the main structure of the full-submersible deep-sea aquaculture platform under the action of water waves, Fluent software is used to numerically simulate regular waves, irregular waves, and strong nonlinear waves, and their effects on the six degrees of freedom motion response of the main structure of the full-submersible deep-sea aquaculture platform are analyzed. The study found that under the towing condition, the smaller the wave direction angle, the more intense the movement. Under the platform's working conditions, the larger the wave direction angle, the more intense the movement.

Key words: fully-submersible; deep-sea aquaculture platform; six degrees of freedom; water wave; wave direction angle

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0 Introduction

The ocean accounts for about 70% of the earth's surface and provides abundant biological, mineral and energy resources, supporting the global economy and human livelihoods. As the largest ecosystem, the ocean not only supplies about one-third of food sources, especially fish and seafood, but also provides a rich source of drugs, seaweed and other biological materials, which promotes the development of many industries. China's No.1 central document for 2023 pointed out that the state should scientifically delimit restricted aquaculture areas, develop large-water-area ecological fishery, build modern marine ranches, and develop deep-sea aquaculture such as deep-water cages and aquaculture ships. China's No.1 central document for 2025 further pointed out that the state should establish a diversified food supply system, promote the high-quality development of the fishery industry, support the development of deep-sea aquaculture, and build marine ranches. The fully submersible deep-sea aquaculture platform is a new type of marine aquaculture structure. It is designed for aquaculture structures in deep-sea environments. It is characterized by being able to be immersed in water to a large extent to improve its stability and safety under harsh marine conditions. Compared with the ordinary deep-sea aquaculture platform, the fully submersible deep-sea aquaculture platform has the following advantages: Strong wind and typhoon resistance. The fully submersible deep-sea aquaculture platform can mostly sink below the sea surface, reducing the exposure to typhoons and bad weather. In contrast, the ordinary deep-sea aquaculture platform may be more vulnerable to the strong winds and

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waves caused by typhoons. The water quality is more stable. Because the full-submersible deep-sea aquaculture platform is located in a deeper sea area, far away from human activities and pollution sources on the shore. The water quality is relatively stable, which helps to provide a more suitable environment for the growth of aquaculture organisms.

With the increasing demand for deep-sea aquaculture, the research on hydrodynamic and motion response of aquaculture platforms is gradually becoming the focus. The in-depth exploration of relevant theories and practices will promote the sustainable development of aquaculture. Wang[1] studied the motion law and force characteristics of the fishing ground platform under the action of waves through physical model tests. The effects of wave height, period and draft depth on the force of the anchor chain and the motion of the fishing ground platform were analyzed respectively, and the dynamic characteristics of the fishing ground platform under the action of pure current and the combined action of wave and current were studied. Wang et al.[2] obtained the stiffness of single anchor leg mooring of deep-water cages by calculating the relationship between the buoy, bottom weight and mooring line of deep-water cages under extreme sea conditions. Therefore, the anti-typhoon scheme of additional mooring line is proposed innovatively. Lin et al.[3] used a self-developed integrated system to calculate and analyze the hydrodynamic force of the offshore aquaculture platform, which solved the problem of poor versatility of each software in independent calculation, and evaluated the positioning ability of the mooring used. Chen[4] analyzed the motion response of the aquaculture platform for the same wave direction angle, summarized its motion law, and provided a calculation reference for the optimization of the mooring system. Yuan[5] checked the strength of the overall structure of the deep-sea cage platform under severe sea conditions, and calculated the strength of the key joints. In order to study the whole process stability scheme of deep-sea aquaculture platform, the platform stability and hydrodynamic performance of towing condition, self-preservation condition and operation condition were calculated respectively[6]. Wang[7] conducted an in-depth study on the multi-body coupling hydrodynamics of aquaculture vessels and cages. It was found that when the mooring point of the cage was set at the stern, the motion response of the aquaculture vessel decreased, but the drift radius and mooring force of the cage increased. Lu et al.[8] calculated the influence of different viscous damping on the hydrodynamic characteristics of the aquaculture platform for the unique new aquaculture semi-submersible platform. It is concluded that the viscous damping will have a great impact on the motion amplitude of the aquaculture platform, and the viscous effect should be fully considered in practical engineering. Liu et al.[9] used a numerical method based on computational fluid dynamics (CFD) modeling to evaluate the flow field of a new type of cage with shielding device. Ma et al.[10] studied the interference and wave-making performance test of single-row and tandem arrangement of floating aquaculture cages. Liu et al.[11] studied the behavior of circular gravity cages in linear waves. Shi et al.[12] discussed the failure probability of offshore high-density polyethylene cages under typhoon waves. In order to obtain the hydrodynamic performance of the deep-sea aquaculture vessel under the action of pure current, the STAR-CCM+ software was used to numerically calculate the six degrees of freedom motion and pressure of the aquaculture vessel[13]. Ji et al.[14] studied the bottom-mounted aquaculture cages using double-layer netting by combining numerical simulation with model experiments. The results showed that the double-layer netting had a significant attenuation effect on the flow velocity. The flow velocity will change sharply near the cage and form a low-speed zone downstream of the cage. The existence of the side net will accelerate the vortex shedding of the middle column, while the bottom net has little effect on the flow velocity. Wu et al.[15] studied the hydrodynamic performance and motion response characteristics of the semi-submersible cage under the action of steady wind flow and irregular waves. It is concluded that the maximum mooring tension of the cage with netting is about twice as much as the cage without netting, and the horizontal drift range is wider.

Firstly, the model establishment and grid division of the full-submersible deep-sea aquaculture platform will be carried out. Then, the motion response of the full-submersible deep-sea aquaculture platform under the action of regular wave, irregular wave and strong nonlinear wave is simulated, analyzed and studied by numerical simulation. At the same time, this chapter also considers two different working conditions of the fully submersible deep-sea aquaculture platform during transportation and operation, namely the towing condition and the working condition. In order to better understand the motion response characteristics of the fully submersible deep-sea aquaculture platform under the action of water waves with different wave direction angles, three wave direction angles of 0°, 45° and 90° are selected to calculate their effects on the motion response of the fully submersible deep-sea aquaculture platform.

In summary, by analyzing the motion response of the fully submersible deep-sea aquaculture platform, it is possible to evaluate its adaptability to high-wave sea conditions, and then formulate corresponding safety measures and engineering design. At the same time, it can help optimize the layout and operation of the aquaculture system. Therefore, the study of the motion response analysis of the full-submersible deep-sea aquaculture platform in the Yellow Sea under different water waves is a necessary step to ensure the safety, structural stability and equipment performance of the platform. It also provides important safety assessment data for marine engineering projects and helps to develop more effective risk management strategies. It has great importance.

1 Numerical Method

In this paper, CFD software Fluent is used for simulation calculation. We will introduce the numerical analysis method and basic theory of Fluent software used later, including basic control equations and turbulence models. The main structure of full-submersible deep-sea aquaculture platform and six degrees of freedom is shown in Fig.1.

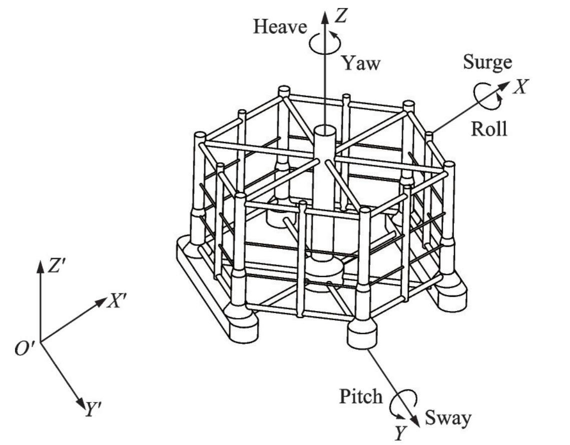

Fig.1 Main structure of full-submersible deep-sea aquaculture platform and six degrees of freedom

1.1 Governing equation

The mass conservation equation, also known as the continuity equation, is one of the basic equations describing the conservation of matter in fluid mechanics. It shows that in a closed system, the quality does not increase or decrease with time.

For incompressible fluid, since the density of the fluid remains unchanged during the movement, the continuity equation is defined as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

where u, v, w represent the velocities in the x, y, and z directions, respectively.

The momentum conservation equation is one of the basic equations describing the conservation of momentum in fluid dynamics. It reflects how the momentum changes with time and space in the flow. According to Newton's second law, the conservation of momentum can be expressed as: Within a given control volume, the rate of change of momentum is equal to the external force applied to the volume. When the fluid is homogeneous and incompressible, the momentum conservation equation is expressed in the form of rectangular coordinate components which can be shown as

$$\begin{cases} \dfrac{\partial u}{\partial t}+u\dfrac{\partial u}{\partial x}+v\dfrac{\partial u}{\partial y}+w\dfrac{\partial u}{\partial z}=-\dfrac{1}{\rho}\dfrac{\partial p}{\partial x}+\dfrac{\mu}{\rho}\nabla^2 u \\ \dfrac{\partial v}{\partial t}+u\dfrac{\partial v}{\partial x}+v\dfrac{\partial v}{\partial y}+w\dfrac{\partial v}{\partial z}=-\dfrac{1}{\rho}\dfrac{\partial p}{\partial y}+\dfrac{\mu}{\rho}\nabla^2 v \\ \dfrac{\partial w}{\partial t}+u\dfrac{\partial w}{\partial x}+v\dfrac{\partial w}{\partial y}+w\dfrac{\partial w}{\partial z}=g-\dfrac{1}{\rho}\dfrac{\partial p}{\partial z}+\dfrac{\mu}{\rho}\nabla^2 w \end{cases} \tag{2}$$

where g represents the acceleration of gravity, p the pressure, μ the viscosity coefficient of fluid motion, and ρ the constant.

1.2 Turbulent flow model

The turbulence model in this paper is SST k-ω model, and the transport equation is as follows

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\Gamma_k\frac{\partial k}{\partial x_j}\right]+G_k-Y_k+S_k \tag{3}$$

$$\frac{\partial(\rho \omega)}{\partial t}+\frac{\partial(\rho \omega u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\Gamma_\omega\frac{\partial \omega}{\partial x_j}\right]+G_\omega-Y_\omega+D_\omega+S_\omega \tag{4}$$

where G_k is the turbulent kinetic energy generated by the laminar velocity gradient, and it is generated by the ω equation; Γ_k and Γ_ω indicate the diffusivity of k and ω, Y_k and Y_ω are turbulent due to diffusion, and S_k and S_ω are user-defined.

2 Water Wave Case Model Verification

2.1 Validation of regular wave numerical tank model

This section will verify the linear wave numerical pool model, mainly based on the simulation calculation of the aquaculture ship model test by Ref.[16]. The model test is carried out in the China Aviation Industry Special Aircraft Research Institute. This section mainly focuses on the full load condition of its physical test, and compares the calculated values of the simulation software with the test data values. Comparing the simulation results with experimental results, the time history curve of rolling motion is shown in Fig.2 and the time history curve of pitching motion is shown in Fig.3.

According to Fig.2 and Fig.3, it can be seen that overall numerical simulation results are in good agreement with experimental results. Simulation values can well reflect the motion response of the model structure under the action of regular waves.

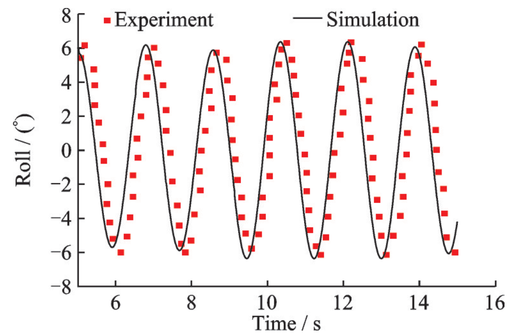

Fig.2 Comparison of roll motion time history curves under the verification of regular wave

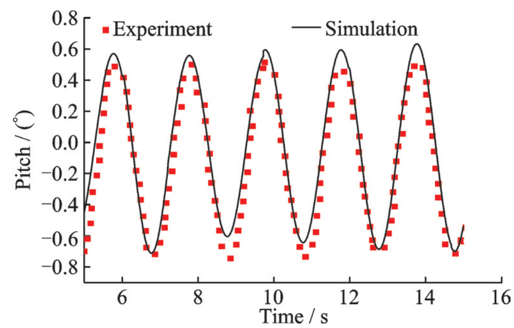

Fig.3 Comparison of pitch motion time history curves under the verification of regular wave

2.2 Validation of irregular wave numerical tank model

This section will verify the irregular wave numerical pool model, mainly based on LS17-2 semi-submersible platform model test for simulation calculation[17], comparing the simulation software calculation value and test data value. The test is completed in the State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University. Simulation results are compared with experimental results, and the time history curves of heave motion are shown in Fig.4.

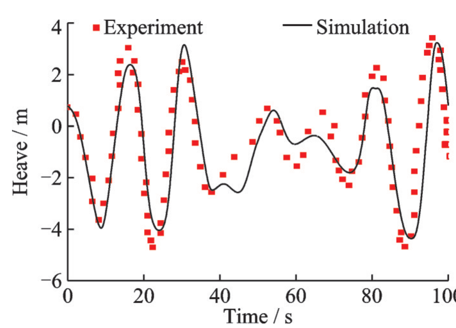

Fig.4 Comparison of heave motion time history curves under the verification of irregular wave

According to Fig.4, it can be seen that simulation values can well reflect the motion response of the model structure under the action of irregular waves. And the numerical simulation values under the action of irregular waves are in good agreement with experimental results.

2.3 Verification of strong nonlinear wave numerical tank model

In this section, the numerical tank model of strong nonlinear wave is verified. The simulation calculation is mainly based on the freak wave physics experiment of Zhao el al.[18], and the simulation software calculation value and test data value are compared. The physical experiment is carried out in the wave tank of the Institute of Applied Mechanics, Kyushu University. Comparing simulation results with the experimental results, the time history curves of heave motion is shown in Fig.5 and the time history curves of roll motion is shown in Fig.6.

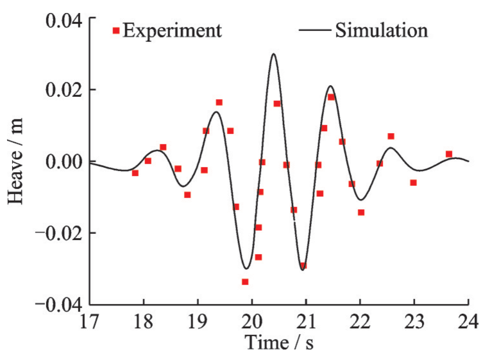

Fig.5　Comparison of heave motion time history curves under the verification of strong nonlinear wave

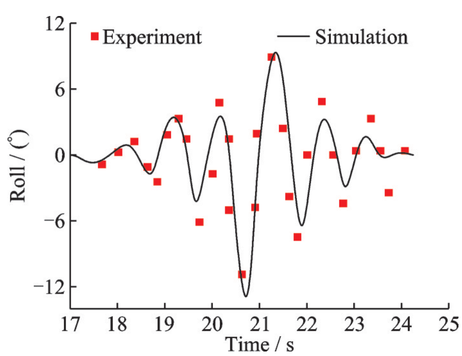

Fig.6　Comparison of roll motion time history curves under the verification of strong nonlinear wave

According to Fig.5 and Fig.6, simulation values can well reflect the motion response of the model structure under the action of strong nonlinear waves.

3 Model Establishment and Calculation Conditions

3.1 Establishment of the main structure model of the full-submersible deep-sea aquaculture platform

When establishing the main structure model of the fully submersible deep-sea aquaculture platform, this paper mainly refers to two classic designs of Deep Blue 1 and Deep Blue 2. As representative full-submersible deep-sea aquaculture platforms, Deep Blue No.1 and Deep Blue No.2 show good stability and motion characteristics in deep-sea environment, so they become important reference objects in this paper. In addition, the main structure of the full-submersible deep-sea aquaculture platform model in this paper also refers to the rigid frame of the semi-submersible aquaculture platform of Liu[19]. In order to save computing resources, this paper will scale all the models used, and the scale ratio is 1∶20. The scale factor λ is equal to 20.

The conversion relationship between the model and the physical quantities of the entity is shown in Table 1.

Table 1　Conversion relationship between physical quantities of models and entities

Project	Symbol	Conversion relationship
Line scale	L_s/L_m	λ
Volume	V_s/V_m	λ^3
Linear velocity	ν_s/ν_m	$\lambda^{1/2}$
Angle	ϕ_s/ϕ_m	1
Period	T_s/T_m	$\lambda^{1/2}$
Frequency	f_s/f_m	$\lambda^{-1/2}$
Density of water	ρ_s/ρ_m	1
Quality (displacement)	Δ_s/Δ_m	λ^3
Force	F_s/F_m	λ^3
Torque	M_s/M_m	λ^4
Moment of inertia	I_s/I_m	λ^5

The two-dimensional three-view of the main structure model of the full-submersible deep-sea aquaculture platform is shown in Figs.7—9.

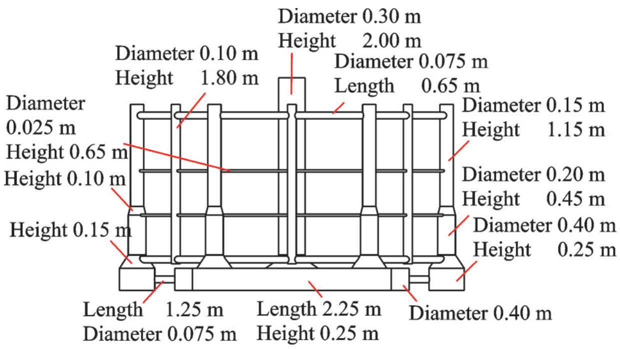

Fig.7 Model front view

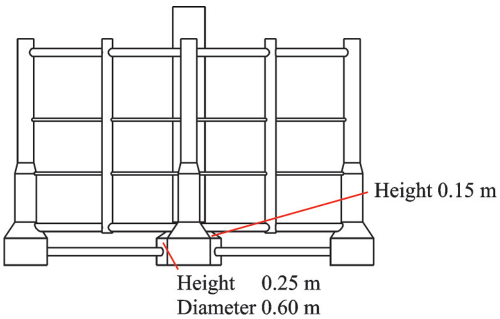

Fig.8 Model side view

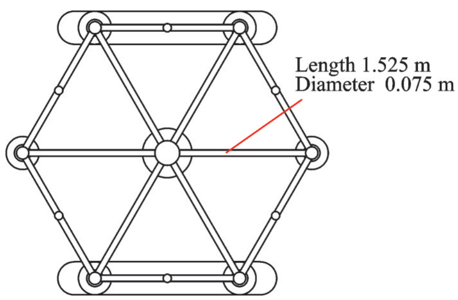

Fig.9 Model top view

3.2 Establishment of numerical pool model

The numerical pool is designed as a cuboid with a length of 30 m, a width of 12 m, and a height of 9 m. The top is 3 m from the water surface and the water depth is 6 m. The first 21 m is the working area and the last 9 m is the wave attenuation area. The specific grid division of the numerical pool is shown in Figs.10—12, and the combined grid of the numerical pool and the aquaculture platform model is shown in Fig.13.

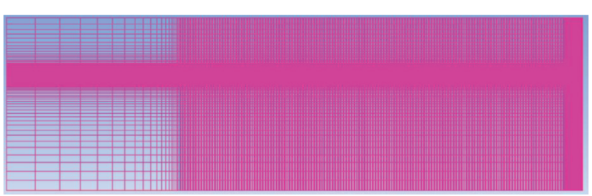

Fig.10 Grid of XOZ plane

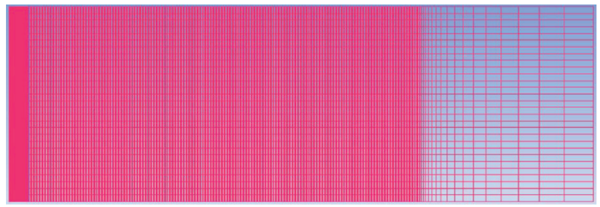

Fig.11 Grid of XOY plane

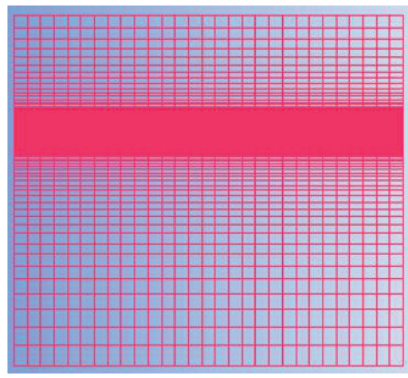

Fig.12 Grid of YOZ plane

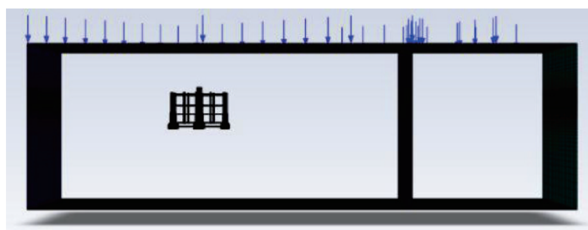

Fig.13 Merge grid diagram of numerical pool and aquaculture platform models

3.3 Calculation settings and calculation conditions

This study is based on Qiu et al.[20] and other spatial and tempora variation characteristics of waves in the Yellow Sea and Bohai Sea. In this paper, the statistical analysis of waves in the Yellow Sea and Bohai Sea are from 2000 to 2019 and the buoy observation data of two measured stations in the Yellow Sea (From January 1, 2011 to December 31, 2017) is used to simulate the real wave situation in the Yellow Sea.

To study the whole process motion response analysis of the full-submersible deep-sea aquaculture platform from structural transportation to working operation, this section will simulate and analyze the motion response of two working conditions of the full-submersible deep-sea aquaculture platform. Structural parameters of the model under towing and working conditions are shown in Table 2.

Table 2 Model structure parameters under different conditions

Name of working condition	Structural parameter	Size
Towing condition	Draft depth/m	0.35
	X-axis inertia tensor/(kg•m^2)	1 030
	Y-axis inertia tensor/(kg•m^2)	1 438
	Z-axis inertia tensor/(kg•m^2)	1 741
Working condition	Draft depth/m	1.80
	X-axis inertia tensor/(kg•m^2)	1 565
	Y-axis inertia tensor/(kg•m^2)	2 185
	Z-axis inertia tensor/(kg•m^2)	2 646

Among them, barycenter coordinates of the full-submersible deep-sea aquaculture platform in the numerical pool are (0, 0, 0.28). The center of gravity is 9 m from the X direction of the pool entrance, 21 m from the X direction of the pool exit, and 6 m from the Y direction of the pool side wall. The two-dimensional diagram of the model with three wave direction angles of 90°, 45° and 0° is shown in Fig.14.

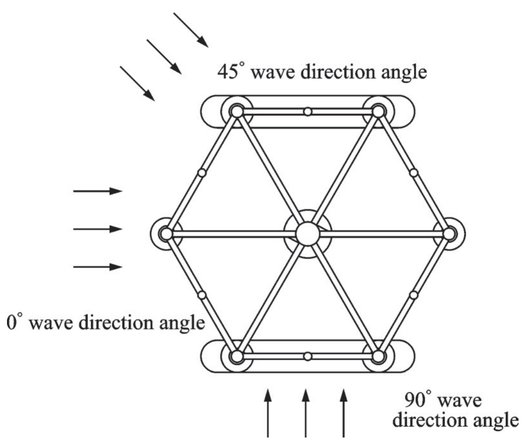

Fig.14 Two-dimensional diagram of the model with different wave angles

(1) Calculation settings and calculation conditions under regular waves

In this paper, the maximum value of the seasonal annual mean value of the average period in the Yellow Sea is 6.5 s (1.45 s after scale reduction), and the wave height is 4 m (0.2 m after scale reduction). Towing conditions and working conditions under three wave direction angles of 90°, 45° and 0° are calculated, respectively.

(2) Calculation settings and calculation conditions under irregular waves

In this paper, the significant wave height of the towing condition is 2 m (0.1 m after scale reduction), and the significant wave height of the working condition is 6 m (0.3 m after scale reduction). Towing conditions and working conditions under three wave direction angles of 90°, 45° and 0° are calculated, respectively. The main information of irregular waves is shown in Table 3.

(3) Calculation settings and calculation conditions under strong nonlinear waves

The strong nonlinear wave in this study is selected as the freak wave. The effective wave height of the background wave train under working conditions is 6 m (0.3 s after scale reduction), and the wave height of the freak wave is greater than 12 m (0.6 m after scale reduction). For the towing condition, the effective wave height of the background wave train is 2 m (0.1 s after scale reduction), and the wave height of the freak wave is greater than 4 m (0.2 m after scale reduction). The freak wave energy is focused on the front of the model, and the occurrence time is 15 s. Three wave direction angles at 90°, 45°, and 0° are considered. The main information of strong nonlinear waves is shown in Table 4.

Table 3 Wave parameters of irregular waves

Target spectrum	Significant wave height	Number of superimposed waves	Median period
ITTC two-parameter wave spectrum	0.1 m/0.3 m	100	1.45

Table 4 Wave parameters of strong nonlinear waves

Target spectrum	Significant wave height	Energy distribution coefficient	Median period
ITTC two-parameter wave spectrum	0.1 m/0.3 m	0.4	1.45

4 Results and Discussion

The water wave action is one of main external forces faced by the aquaculture platform, which has a significant impact on its motion response. In order to better understand the motion response characteristics of the full-submersible deep-sea aquaculture platform under the action of water waves, this study uses numerical simulation to analyze and study the six degrees of freedom of the full-submersible deep-sea aquaculture platform under the action of regular waves, irregular waves and strong nonlinear waves, which provides an important reference for the optimization of the entire design process and the operational safety of the deep-sea aquaculture platform.

4.1 Motion response analysis under towing condition

Referring to the latest towing operation notice issued by the Maritime Safety Administration, this paper uses the average towing speed of 4 knots/h in recent years. Unit conversion: 4 knots/h is approximately equal to 2.06 m/s (0.46 m/s after scaling).

(1) Motion response under regular waves

Under the towing condition of the aquaculture platform under the action of regular waves, the rolling, pitching, and heaving of the aquaculture platform models with wave direction angles of 90°, 45° and 0° are compared and analyzed. The time history curves of rolling, pitching and heaving motion are shown in Figs. 15—17. According to Figs.15—17, it can be seen that under the towing condition of the aquaculture platform under the action of regular waves, the roll, pitch and heave of the aquaculture platform model with wave direction angles of 90°, 45° and 0° are distributed periodically. The rolling, pitching and heaving of the aquaculture platform model generally maintain the law that the wave direction angle of 90° is less than those of 45° and 0°. There are slight differences in the rolling, pitching and heaving cycles of aquaculture platform models with wave angles of 90°, 45° and 0°.

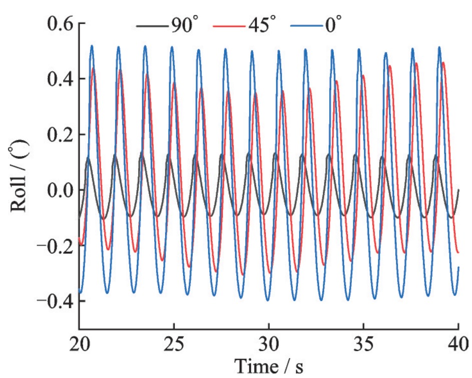

Fig.15 Comparison of roll motion time history curves under regular wave in towing condition

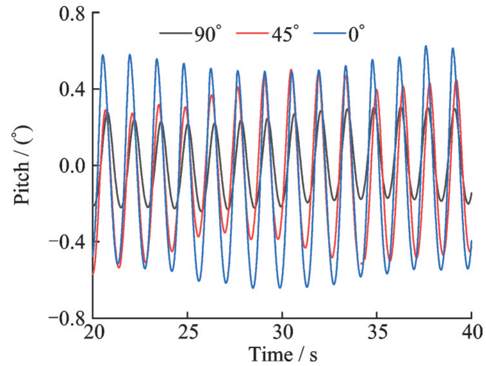

Fig.16 Comparison of pitch motion time history curves under regular wave in towing condition

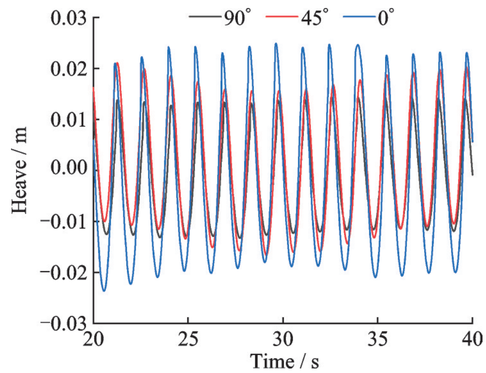

Fig.17 Comparison of heave motion time history curves under regular wave in towing condition

(2) Motion response under irregular waves

Under the towing condition of the aquaculture platform under the action of irregular waves, the comparison of the time history curves of rolling, pitching and heaving motion are shown in Figs. 18—20. According to Figs.18—20, it can be seen that it is consistent with the above situation under the action of regular waves. There are obvious differences in the contrast period and amplitude of rolling, pitching and heaving of the aquaculture platform models with wave angles of 90°, 45° and 0°.

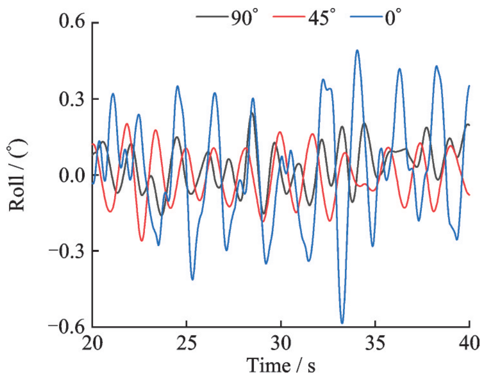

Fig.18 Comparison of roll motion time history curves under irregular wave in towing condition

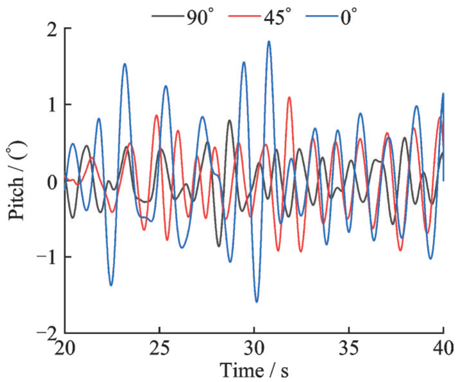

Fig.19 Comparison of pitch motion time history curves under irregular wave in towing condition

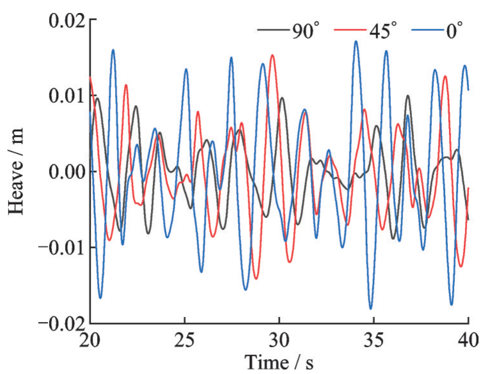

Fig.20 Comparison of heave motion time history curves under irregular wave in towing condition

(3) Motion response under strong nonlinear waves

Under the towing condition of the aquaculture platform under the action of strong nonlinear wave, the time history curves of rolling, pitching and heaving motion are shown in Figs.21—23. According to Figs.21—23, it can be seen that at the 15th second of the strong nonlinear wave, the roll, pitch and heave of the aquaculture platform model with wave

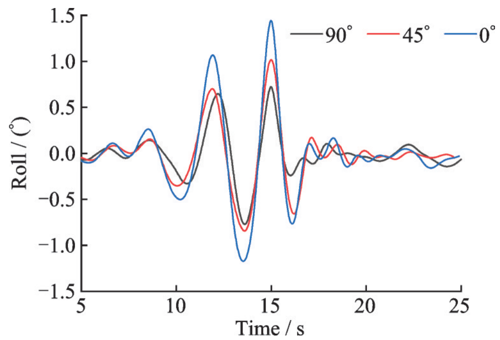

Fig.21 Comparison of roll motion time history curves under strong nonlinear wave in towing condition

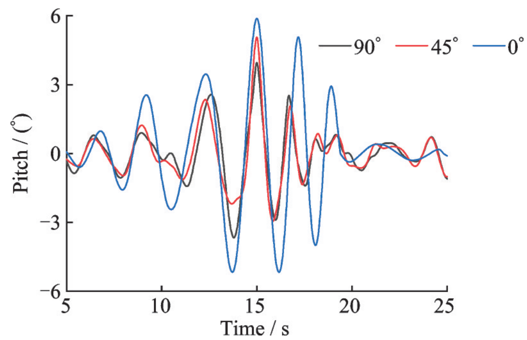

Fig.22 Comparison of pitch motion time history curves under strong nonlinear wave in towing condition

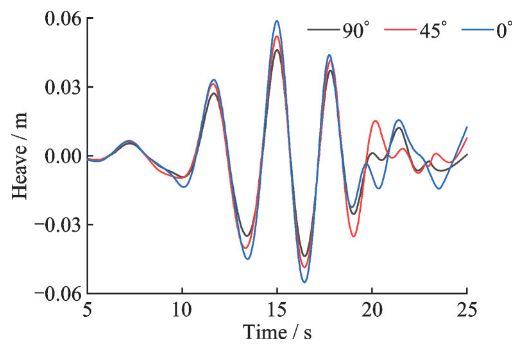

Fig.23 Comparison of heave motion time history curves under strong nonlinear wave in towing condition

direction angles of 90°, 45° and 0° have a surge phenomenon. It is consistent with the above situation under the action of regular wave and irregular wave. The degree of pitch is significantly higher than that of roll.

4.2 Motion response analysis under working condition

(1) Motion response under regular waves

Under the working conditions of the aquaculture platform under the action of regular waves, the roll, pitch and heave motion time history curve comparison diagrams are shown in Figs.24—26. According-

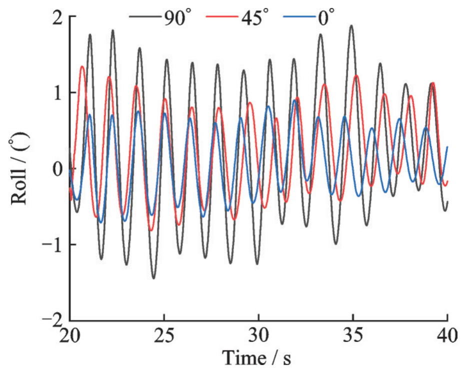

Fig.24 Comparison of roll motion time history curves under regular wave in working condition

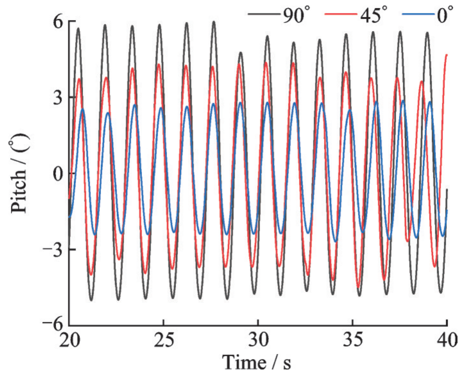

Fig.25 Comparison of pitch motion time history curves under regular wave in working condition

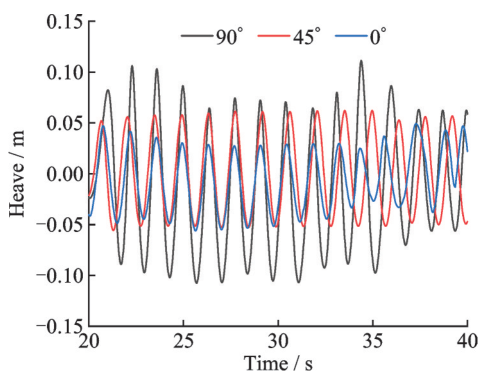

Fig.26 Comparison of heave motion time history curves under regular wave in working condition

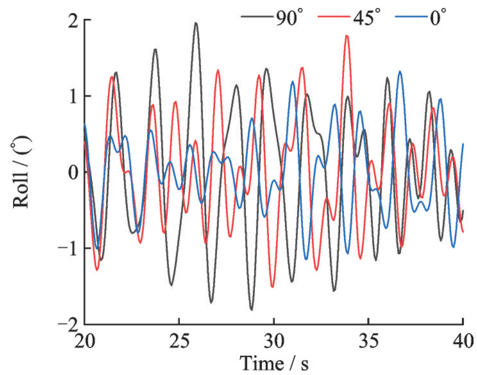

Fig.27 Comparison of roll motion time history curves under irregular wave in working condition

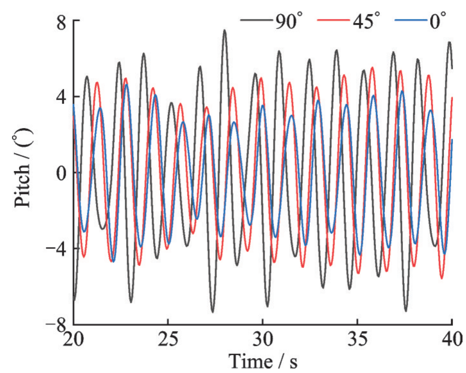

Fig.28 Comparison of pitch motion time history curves under irregular wave in working condition

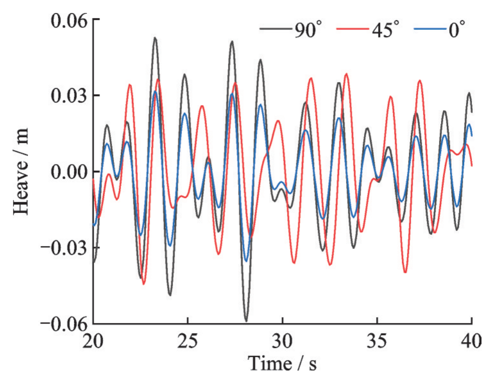

Fig.29 Comparison of heave motion time history curves under irregular wave in working condition

ing to Figs. 24—26, it can be seen that the roll, pitch and heave of the aquaculture platform model generally maintain the law that the wave direction angle of 90° is greater than those of 45° and 0°.

(2) Motion response under irregular waves

Under the working conditions of the aquaculture platform under the action of irregular waves, the roll, pitch and heave motion time history curve comparison diagrams are shown in Figs.27—29. According to Figs. 27—29, it is consistent with the above situation under the action of regular waves. There are obvious differences in the contrast period and amplitude of roll, pitch, and heave of the aquaculture platform model with the wave direction angles of 90°, 45°, and 0°.

(3) Motion response under strong nonlinear waves

Under the working conditions of the aquaculture platform under the action of strong nonlinear waves, the time history curves of rolling, pitching, and heaving motion are shown in Figs.30—32. According to Figs.30—32, it can be seen that in the preset 15 s, the rolling, pitching and heaving of the aquaculture platform model all show a surge on schedule. The amplitude of rolling, pitching and heaving of the aquaculture platform model is consistent with the above situation under the action of regular waves and irregular waves.

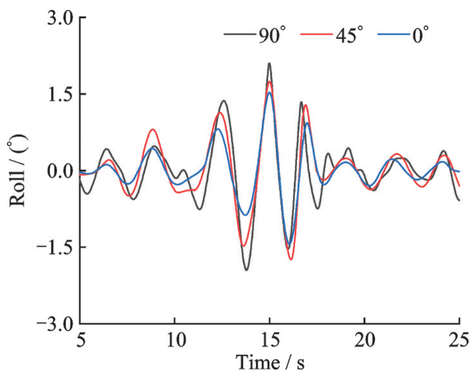

Fig.30 Comparison of roll motion time history curves under strong nonlinear wave in working condition

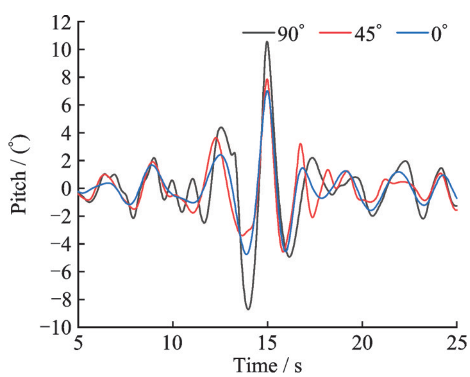

Fig.31 Comparison of pitch motion time history curves under strong nonlinear wave in working condition

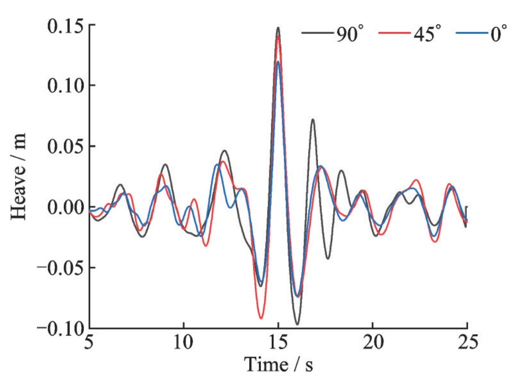

Fig.32 Comparison of heave motion time history curves under strong nonlinear wave in working condition

This paper mainly focuses on the numerical simulation analysis of the motion response of the full-submersible deep-sea aquaculture platform under the action of water waves under towing conditions and working conditions. Among them, the influence of the regular wave, the irregular wave and the strong linear wave on the motion response of an aquaculture platform under towing condition and working condition is discussed and analyzed, respectively. At the same time, three cases of wave direction angles of 90°, 45° and 0° are also discussed respectively. The main conclusions are as follows:

(1) Under the towing conditions of regular waves, irregular waves and strong nonlinear waves, the rolling, pitching and heaving amplitudes of the aquaculture platform model at the wave angle of 90° are less than those at the wave angles of 45° and 0°.

(2) Under the working conditions of aquaculture platform under the action of regular wave, irregular wave and strong nonlinear wave, the amplitude of rolling, pitching and heaving of the aquaculture platform model at the wave angle of 90° is greater than that at the wave direction angles of 45° and 0°.

5 Conclusions

When the full-submersible deep-sea aquaculture platform is towing with the wave, the amplitude of motion is more intense, whether it is regular wave, irregular wave or strong nonlinear wave. The wave motion of the full-submersible deep-sea aquaculture platform under working conditions is relatively stable, but the motion amplitude is more intense when the wave is moving. The calculation results of this experiment provide important experimental data support for the dynamic characteristics of the aquaculture platform under different waves. The specific significance includes as follows: (1) The study find that the influence of different wave direction angles on the stability of the aquaculture platform provides a theoretical basis for the design and optimization of the structure and layout in the future, so as to improve the anti-wave ability and safety of the platform. (2) By analyzing the response characteristics of the platform under different wave conditions, it can provide guidance for the operation and management of the aquaculture platform, especially in terms of site selection and operation strategy, to help decision makers reasonably avoid adverse wave effects. (3) This study provides an experimental basis for the safety assessment of related aquaculture platforms in the future, promotes the research on the safety and reliability under the change of marine environment, and provides support for the formulation of industry standards.

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Author contributions Mr. **FENG Ran** was responsible for the main parts of the paper, and the overall design and implementation of this study, independently conducting literature review and collecting and analyzing experimental data. Dr. **FRANCK AUREL Likeufack Mdemaya** assisted in experimental design and data analysis, and made comprehensive revisions and polishing to the final manuscript. Prof. **XU Gang** was responsible for the overall guidance and supervision of the research topic, providing important theoretical support and research framework, and conducting important reviews and revisions of the structure and content of the paper. All authors commented on the manuscript draft and approved the submission.

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水波作用下全潜式深海养殖平台主体结构运动响应数值模拟分析

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摘要：人类对海洋资源的开发利用正逐步走向深远海，深海养殖平台应运而生，以满足水产养殖和粮食安全的需求。为了更好地理解全潜式深海养殖平台主体结构在水波作用下的运动响应特性，采用Fluent软件数值模拟规则波、不规则波和强非线性波以及其对全潜式深海养殖平台主体结构六自由度运动响应的影响特性和规律。研究发现，养殖平台主体结构在拖航工况下，浪向角越小，运动的越剧烈；养殖平台主体结构在工作工况下，浪向角越大，运动的越剧烈。

关键词：全潜式；深海养殖平台；六自由度运动；水波；浪向角