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# A Multi-Body Structure Optimization and Fully Coupled Hydrodynamic Simulation Method for Marine Semi-Submersible Equipment

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**Abstract.** For marine semi-submersible equipment, based on the AQWA platform, the intelligent optimization design of key hydrodynamic parameters is realized by integrating Matlab algorithm development and data interaction module. The general complex kinematic pair model is constructed by the equivalent model to realize the modeling and hydrodynamic calculation of complex relative motion mechanism. Through the secondary development of the data interface, the full coupling simulation calculation of multidisciplinary and multidisciplinary fields is realized.

**Keywords:** intelligent optimization, fully coupled simulation, AQWA, semi-submersible equipment.

## 1. Introduction

With the development and utilization of marine resources more and more widely, the application of marine semi-submersible equipment is also developing in the direction of systematization and refinement. The application of marine semi-submersible equipment inevitably requires comprehensive hydrodynamic calculation and verification. For systematic and refined marine engineering equipment, it is necessary to consider the influence of multi-body coupling[1-3], complex relative motion[4-5], multi-disciplinary and Effects of multidisciplinary coupling[6-7]. At present, the mainstream hydrodynamic simulation platforms include WAMIT, AQWA, SESAM, etc. Among them, WAMIT only has the ability of hydrostatic simulation analysis, and does not have the function of time domain calculation ; SESAM has the ability of hydrostatic analysis and time domain simulation, but it is relatively closed, and it is difficult to realize multidisciplinary fully coupled simulation analysis and intelligent optimization design. AQWA has the functions of hydrostatic simulation and time domain calculation, but it has limitations in the calculation of multi-body composite relative motion and cannot be directly coupled with other systems. Kousika Kumar A et al.developed a system coupling simulation model of wave energy converter based on Simulink[8], but its hydrodynamic model is a simplified equation, which can not realize the calculation of complex multi-body

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structure. Pengyuan Sun et al.studied the performance of wave energy generation device based on AMESim [9], but the capture device is equivalent to sine curve, and the coupling effect of capture device and irregular wave on the system is not studied. S Juwairiyah et al.studied the application characteristics of constant pressure scheme in hydraulic PTO (Power Take Off) through simulation and experiment[10], but neglected the coupling effect of capture device on hydraulic PTO system. Therefore, it is necessary to develop and integrate based on the existing hydrodynamic simulation platform to meet the calculation requirements of multi-body coupling, complex relative motion, multi-disciplinary and multi-disciplinary fields.

The purpose of this study is : for marine semi-submersible equipment, based on the AQWA platform, the Matlab algorithm development and data interaction module integration are integrated to realize the intelligent optimization design of key hydrodynamic parameters ; the general kinematic pair model is constructed by the equivalent model to realize the modeling and hydrodynamic calculation of complex relative motion mechanism. Through the secondary development of the data interface, the full coupling simulation calculation of hydrodynamic and multidisciplinary fields including hydraulic, electrical and control is realized. A set of hydrodynamic intelligent optimization, complex mechanism motion simulation and multidisciplinary and multi-field fully coupled hydrodynamic simulation calculation methods suitable for systematic and refined marine semi-submersible equipment are established.

## 2. Research Content and Implementation Method

For marine semi-submersible equipment, the research content of this paper involves three aspects: structure, mechanism and system. In terms of structure, it mainly involves intelligent optimization of hydrodynamic parameters of multi-body structure. In terms of mechanism, it mainly involves equivalent modeling of multi-body complex kinematic pairs. In terms of system, it mainly involves multi-disciplinary and multi-disciplinary fully coupled hydrodynamic simulation calculation.

### *2.1 Intelligent Optimization of Hydrodynamic Parameters of Multi-Body Structure*

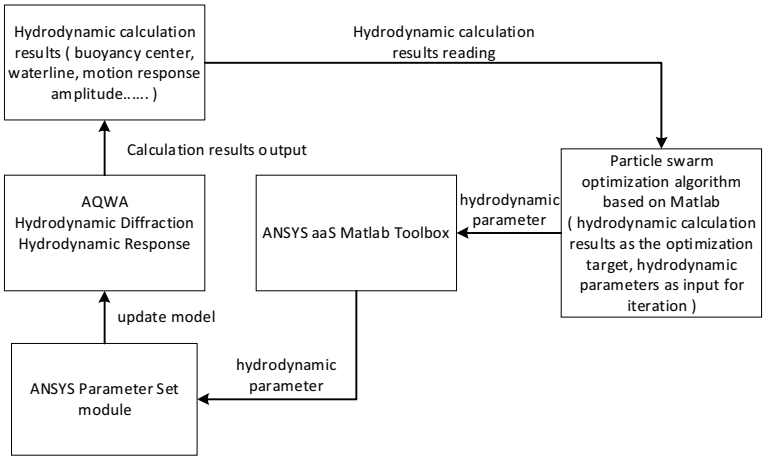


**Fig. 1.** Block diagram of intelligent optimization method of structural hydrodynamic parameters

AQWA uses the boundary element analysis method to calculate the hydrodynamic force of the structure, so the hydrodynamic parameters of the structure mainly include the size, mass, center of mass, moment of inertia and other parameters of the structure. Based on AQWA, the hydrodynamic characteristics of multi-body structures can be analyzed and calculated. The calculation results include buoyancy center, water line, stiffness in all directions, stability, added mass, motion response amplitude, etc. In view of the many hydrodynamic parameters of multi-body and complex structures, the complex influence mechanism and the large amount of optimization calculation, this paper proposes an intelligent optimization method of structural hydrodynamic parameters as shown in figure 1.

In this paper, an intelligent optimization algorithm is developed based on Matlab, in which the hydrodynamic characteristics are taken as the optimization target and the hydrodynamic parameters are taken as the input. The optimization algorithm first gives the initial value of the structural hydrodynamic parameters according to the structural characteristics, and communicates with the ANSYS Parameter Set through the ANSYS aaS Matlab Toolbox. The AQWA updates the model according to the transferred hydrodynamic parameters, and performs structural hydrostatic calculation and time domain calculation to output the hydrodynamic characteristics calculation results. Matlab reads the calculation results of hydrodynamic characteristics and compares them with the hydrodynamic characteristics target. If the optimization target is met, the calculation is completed. If the optimization goal is not met, the optimization algorithm iterates the hydrodynamic parameters according to the set parameter range and the target difference, and then passes them to AQWA for calculation until the calculation results meet the optimization goal. The calculation flow chart is shown in Figure 2.

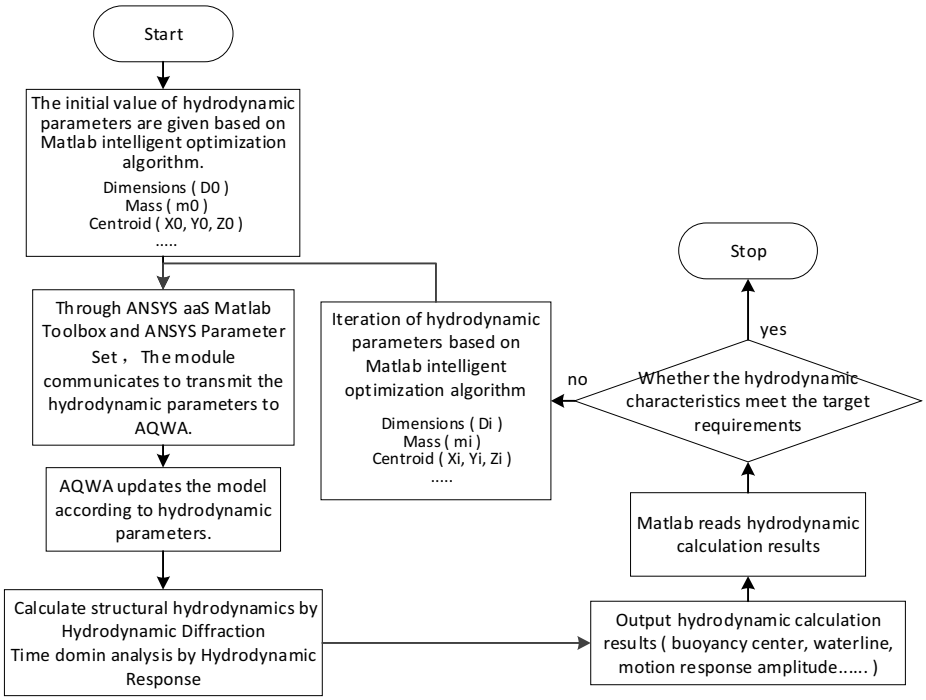


**Fig. 2.** Flow chart of intelligent optimization calculation of structural hydrodynamic parameters

### 2.2 Equivalent Modeling of Multi-Body with Complex Kinematic Pair

At present, in the mainstream hydrodynamic simulation platform, the modeling tools for multi-body relative motion are limited, mainly limited to the modeling of motion pairs between multi-bodies. AQWA provides modeling tools for spherical hinges, cross hinges, hinges, fixed joints, and Fender multi-body joints, but there are still deficiencies in constructing complex multi-body relative motion models, such as the lack of cylindrical pairs and sliding pairs. Based on the Fender tool, this topic expands the AQWA multi-body relative motion modeling function by equivalently modeling the cylindrical pair and the sliding pair to adapt to the complex mechanism motion.

#### 2.2.1 Equivalent Modeling Method of Cylindrical Pair

As shown in figure 3, the equivalent model method of cylindrical pair based on Fender is constructed.

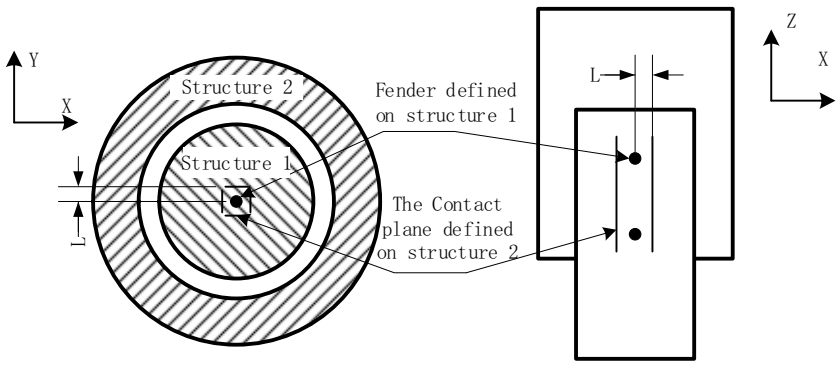


**Fig. 3.** Cylindrical pair equivalent model diagram

The cylindrical pair needs to define two sets of Fenders on two XY planes with a certain distance along the Z-direction at least, and each group is at least 90 ° apart to define four Fenders. The Fender Connection Point of four Fenders in a single group is the same point and distributed in the center line of structure 1. The Contact Plane of four Fenders is defined on structure 2, the normal angle between adjacent planes is 90 °, and the Fender Connection Point on structure 1 is L. According to the mechanical model of Fender, it can define the elastic force, friction force and damping force between Fender Connection Point on structure 1 and Contact Plane on structure 2.

Elastic force equation ( compression direction ):

$$T = \begin{cases} k_1\Delta L + k_2(\Delta L)^2 + k_3(\Delta L)^3 + k_4(\Delta L)^4 + k_5(\Delta L)^5 & if\ \Delta L > 0 \\ 0 & if\ \Delta L \leq 0 \end{cases} \tag{1}$$

frictional force equation:

$$F_f = \mu T \tag{2}$$

damping force equation:

$$F_d = \beta K_f \frac{dL_d}{d_t} \tag{3}$$

Where $k_j (j = 1,2 \ldots 5)$ is the stiffness coefficient, μ is the friction coefficient, β is the damping coefficient, $L_d$ is the actual distance between the Fender Connection Point and the Contact Plane, $\Delta L = L - L_d$

When the structure 1 moves or rotates around the X or Y direction relative to the structure 2 in the X or Y direction, the ΔL of one or more of the eight Fenders in the two groups increases, and the elastic force and damping force are generated between the Fender Connection Point and the Contact Plane ; when the structure 1 moves along the Z direction or around the Z axis relative to the structure 2, ΔL is basically unchanged or less than 0, so it can move freely. The equivalent modeling of the cylindrical pair can be realized by setting the stiffness coefficient, friction coefficient and damping coefficient.

### *2.2.2 Equivalent Modeling Method of Sliding Pair*

The sliding pair equivalent model method based on Fender is shown in Figure 4.

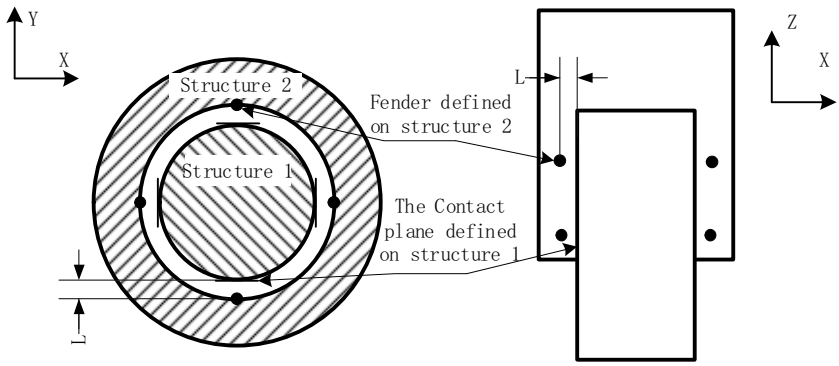


**Fig. 4.** Equivalent model diagram of sliding pair

The sliding pair needs to define two sets of Fenders on two XY planes with a certain distance along the Z direction at least, and each group is at least 90 degrees apart to define four Fenders. The Fender Connection Point of the single group of four Fenders is four points, distributed on the surface of the sliding contact between the structure 2 and the structure 1 ; the Contact Plane of four Fenders is defined on structure 1, the normal angle between adjacent planes is 90°, and the Fender Connection Point on structure 2 is L. The mechanical model of Fender is consistent with the above cylindrical pair.

When the structural component 1 moves along the X or Y direction, rotates around the X or Y direction, or rotates around the Z direction relative to the structural component 2, the $\Delta L$ of one or more of the eight Fenders in the two groups has an increased change, and the elastic force and damping force are generated between the Fender Connection Point and the Contact Plane. When the structure 1 moves in the Z direction relative to the structure 2, $\Delta L$ is basically unchanged, so it can move freely. By setting the stiffness coefficient, friction coefficient and damping coefficient, the equivalent modeling of the sliding pair can be realized.

Based on the above technical scheme, the equivalent modeling of more complex motion pairs can be explored and studied.

### *2.3 Technology Research of Multidisciplinary Fully Coupled Hydrodynamic Simulation*

Marine engineering equipment is developing towards the trend of system integration, and the demand for analysis of coupled hydrodynamic response characteristics of equipment system in marine environment is becoming more and more intense. The mainstream hydrodynamic simulation analysis platform can not be directly integrated with the third-party computing platform. Based on the secondary development of AQWA and AMESim, this paper realizes multi-disciplinary fully coupled hydrodynamic simulation calculation, which can realize the hydrodynamic response characteristics analysis of equipment system and the intelligent optimization design of system parameters in complex marine environment.

The block diagram of the multidisciplinary fully coupled hydrodynamic simulation method proposed for this topic is shown in Figure 5. Based on research content 2, multiple structural components are connected by multi-body motion pairs, and the hydrodynamic model of component mechanism is established. Based on the research content 1, combined with the hydrostatic hydrodynamic characteristic parameters of each structure and the time domain response characteristic parameters of the mechanism, the hydrodynamic model parameters of each structure are optimized. Based on the AQWA and AMESim fully coupled data interaction interface program developed by Python, the system model based on AMESim ( including hydraulic system, electrical system, electronic control system, etc. ) and the hydrodynamic time domain model based on AQWA are combined to realize the fully coupled simulation calculation. Based on the system parameter optimization algorithm developed by Python, the system model parameters can be optimized by combining the hydrodynamic time-domain response parameters of the mechanism and the system response parameters. After a round of optimization calculation, the optimization range of the structural hydrodynamic model parameters can be reset when the calculation results are not ideal.

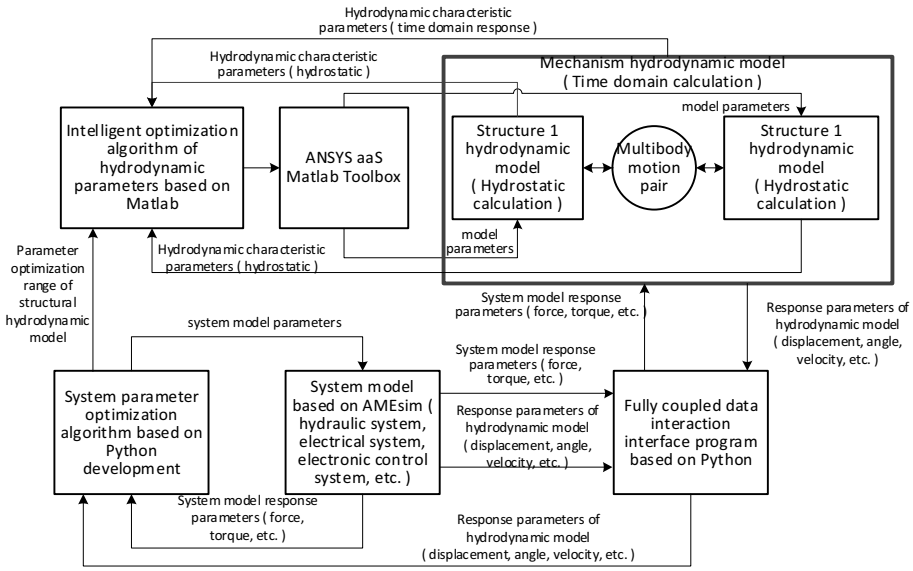


**Fig.5.** Block diagram of multidisciplinary fully coupled hydrodynamic simulation method

Through the above scheme, the multidisciplinary fully coupled simulation optimization design from structure to system of complex floating or semi-submersible marine equipment system can be realized.

## 3. Verification

In this paper, taking the wave energy power generation device as an example, based on the above method, the intelligent optimization model of the capture device shape, the multi-body motion pair equivalent model and the multi-body fully coupled simulation analysis model are constructed.

### *3.1 Intelligent Optimization Model*

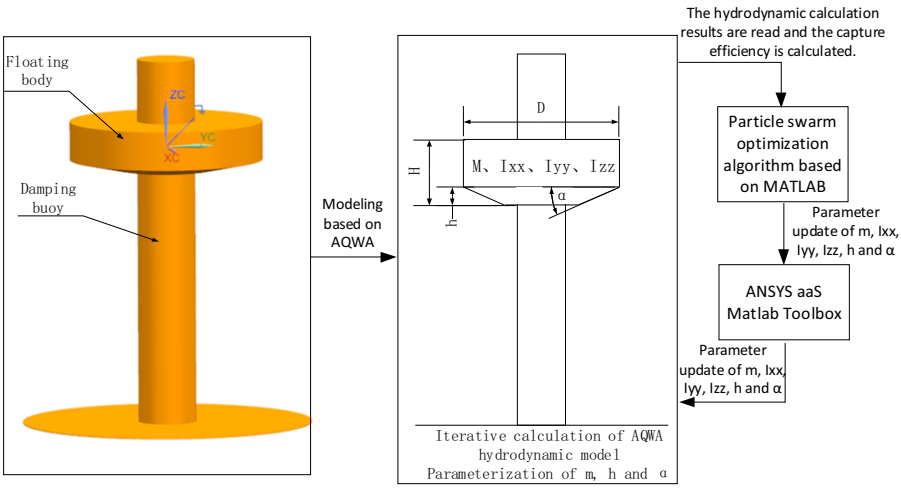


**Fig. 6.** Intelligent optimization model

The intelligent optimization model is mainly used to optimize only one or several parameters of the capture device under certain conditions, so as to maximize the capture efficiency of the device in a specific marine environment. Figure 6 is an example of the intelligent optimization model constructed according to the proposed method. The capture device o the wave energy generation device in the figure mainly includes a floating body and a damping buoy. The main parameter affecting its capture efficiency is the shape and quality parameters of the floating body. The parametric model of the capture device is established based on AQWA, in which the mass m of the floating body, the cone height h of the conical floating body, the taper α of the conical floating body and the moment of inertia Ixx, Iyy and Izz of the floating body are parametric variables. Intelligent optimization calculation processes are as follows :

- The AQWA hydrodynamic model calculates the response of the power generation device under specific wave conditions according to the set initial value.

- The particle swarm optimization algorithm based on MATLAB is used to read the AQWA hydrodynamic calculation results. The capture power is calculated according to the force between the floating body and the damping buoy and the relative motion speed.

The input power of the wave is calculated according to the wave condition and the diameter D of the floating body.

- The optimization algorithm evaluates the deviation between the acquisition efficiency and the target value of the optimization algorithm, and iteratively updates the parameterized variables.

- The iteratively updated parametric variables are transmitted to the AQWA hydrodynamic model through ANSYS aaS MATLAB Toolbox, and the geometric parameters of the capture device are updated.

- AQWA recalculates the hydrodynamic response characteristics for the updated capture device model to achieve a cycle. After multiple iterations, the optimal floating structure parameters can be calculated to achieve the capture efficiency closest to the target value.

### *3.2 Equivalent Model of Motion Pair*

In order to simulate the linear motion of the floating body relative to the damping buoy under the action of waves, the sliding pair of the Fender component is shown in figure.7. In order to ensure the stability of the motion, four Fenders are constructed on the upper and lower surfaces of the floating body, with an interval of 90 ° between each Fender.

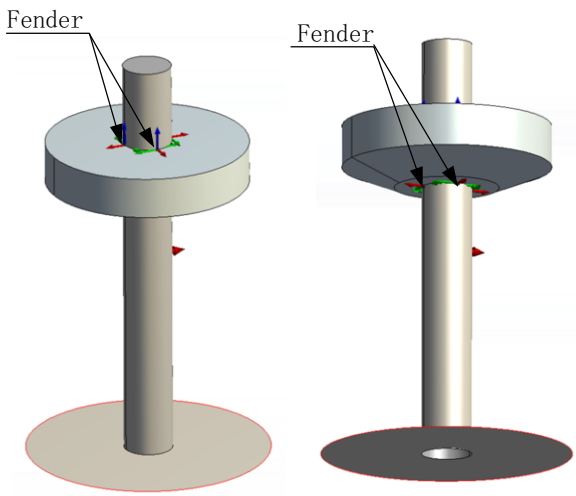


**Fig. 7.** Equivalent model of motion pair

### *3.3 Simulation Model of Multidisciplinary Fully Coupled Hydrodynamic*

In order to match the parameters between the hydraulic PTO and the capture device, a multidisciplinary fully coupled hydrodynamic simulation model shown in Figure 8 is constructed based on AQWA, AMESim and Python. The hydrodynamic model of the capture device is constructed based on AQWA, the hydraulic PTO system model is constructed based on AMESim, and the data interaction module between AQWA and AMESim is constructed based on Python. The calculation process is as follows :

- The data interaction module reads the centroid position of the buoy and the damping buoy from AQWA, and calculates its relative position and relative speed ;

- The data interaction module passes the relative displacement and relative velocity between the floating body and the damping buoy to the hydraulic PTO system in AMESim through the Shared Memory module.

- The data interaction module reads the cylinder output of the hydraulic PTO system and transmits it to the AQWA hydrodynamic model, which is applied between the floating body and the damping buoy.

- Complete a time step calculation, enter the next time step, until the calculation is completed.

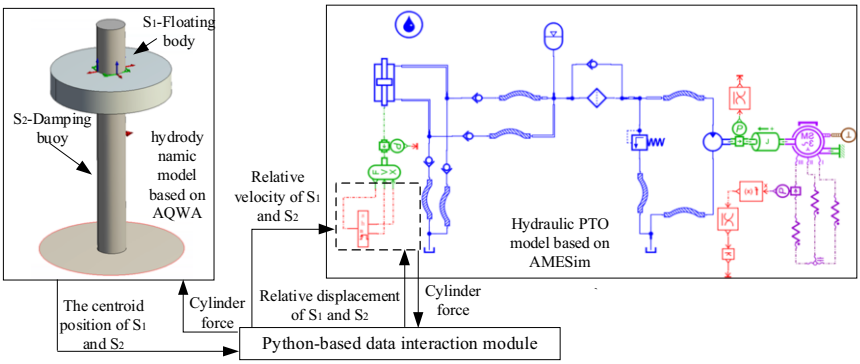


**Fig. 8.** Multidisciplinary fully coupled hydrodynamic simulation model

## 4 Conclusion

In this paper, the simulation calculation method of marine semi-submersible equipment is taken as the research object. The intelligent optimization method of multi-body structure hydrodynamic parameters is proposed for the structure. The equivalent modeling method of multi-body complex motion pair is proposed for the mechanism. The multi-disciplinary fully coupled hydrodynamic simulation calculation method is proposed for the system. Taking the wave energy generation device as an example, the practical application of the above method is described. The calculation method proposed in this paper can analyze and calculate the multi-body complex system of marine semi-submersible equipment more comprehensively, which can effectively improve the design and optimization ability of marine engineering equipment and adapt to the future development trend. Improve the performance and state prediction ability of marine engineering equipment in complex marine environment, and reduce the risk of equipment application. Shorten the equipment design, test verification cycle, improve the efficiency of scientific research and design personnel. The method proposed in this paper can be applied to the design of wave power generation device, ocean current power generation device, observation buoy design, semi-submersible platform design, ship design and other fields, and has wide application value.

## Reference

[1] S.K. Du, J. Fan. Study on Hydrodynamic Interaction of Multi-body in Float-over Installation. Shipbuilding of China, 63(06): 57-68 (2022).

[2] R. Luo, Z.Q. Liu, Z.Y. Peng. Hydrodynamic response analsis of multi-body floating platform in different wave direction angles. Acta Scientiarum Naturalium Universitatis Sunyatseni, 57(06): 71-76 (2018).
[3] D.Q. Gao, Y. Liu, Y.F. Kou. Computational Research on the Coupling Dynamic Response of Multi-Body System for Wreck Salvage. SHIP ENGINEERING, 44(05): 59-64 (2022).
[4] H.W. Zhang, W. Hou, X.M. Wang, S.X. Wang, J. Liang. The Multibody M odeling and Dynamic Simulation of the AUV with the Capacity of Soft Landing. Ocean Technology, 25(4): 6-10 (2006).
[5] Y.Q. Liu, N.X. Ren, J.P. Ou. Coupled dynamic response analysis of a large floating structure system with hybrid modules. The Ocean Engineering, 40(01): 21-28 (2022).
[6] Z.Q. Hu. A Review on the Key Technologies of Dynamic Response Prediction of Floating Offshore Wind Turbines. Naval Architecture And Ocean Engineering, 36(06): 1-13 (2020).
[7] W.H. Li, C. Wang. Multi science cross design optimization system for ship hydrodynamic performance. SHIP SCIENCE AND TECHNOLOGY, 43(14): 10-12 (2021).
[8] K.A. Kousika, S. Balamurugan. Modeling and Simulation of Point Absorber WaveEnergy Converter. In: i-PACT. Vellore. 1-4 (2019).
[9] P.Y. Sun, Q. Li, H. He, H. Chen, D. Liu. Design and optimization investigation on hydraulic transmission andenergy storage system for a floating-array-buoys wave energy converter. Energy conversion & management, 235: 113998.1- 113998.17 (2021).
[10] S. Juwairiyah, M.Z. Ibrahim, A. Albani, Z.M. Yusop, S. Mohad. The Simulation and Experimental Study of Hydraulic Transmission with Constant-pressure Scheme for WaveEnergy Converter Application. In: Materials Science and Engineering. Melbourne. 605: 012007.1 -012007.9 (2019).