Three-dimensional simulation of floating wave power device

Xixi Pan[1, a], Shiming Wang[1, b], Yongcheng Liang[1, c]

[1] Department of College of Engineering Science and Technology, Shanghai Ocean University, Shanghai, 201306, China[2]Department of Electrical Engineering and Automation, Luoyang Institute of Science and Technology, Luoyang, 471023, China

[a]email: 446802183@qq.com, [b]email:smwang@shou.edu.cn, [c]email:ycliang@shou.edu.cn

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Abstract. Due to large amounts of traditional energy consumption, faces increasingly dry up, people began to look for alternative new energy. And waves in the ocean energy can make a very good substitute, so countries began to study wave energy power generation. In the study of wave power device, the movement and stress of the floating body and have a crucial impact on device. In this paper, floating body movement and the stress distribution in three-dimensional sink are research, the stress of the floating body and get better floating body model is analyzed, which is advantageous to the device for wave absorption use.

Introduction

According to statistics and the current world energy consumption level, is expected in 140, all the energy will be consumed[1-2]. Therefore it is necessary to find and develop renewable energy. And marine accounts for 71% of the surface of the earth. There is a huge energy. Wave energy accounts for five of the ocean.

The study of wave energy power generation and the development of the wave energy use of new technology have good prospects and important significance. If we can reasonable development and utilization of wave energy, it will bring to people's life positive role and make human life more green environmental protection.

While in the study of wave energy power generation device, the simulation and experiment should be used. Because of the complex and time-consuming, and if the floating body model is large in size, it is more difficult to do the experiment. In this paper, the floating body wave energy power plant, using Flow-3D[3], the establishment of a three-dimensional simulation of the floating body in three-dimensional tank force, its analysis and research.

Mathematical Model

The control equation of wave motion

The motion of the fluid also has many kinds of forms, and a kind of wave motion is one of the. Therefore, the wave motion must satisfy the basic equations of fluid motion, including continuity equation and motion equation of fluid motion.

1)The continuity equation

The conservation of mass is a rule of must follow any object motion[4], according to the mass conservation theorem can be continuous equation of fluid:

$$\frac{\partial\left(u_x A_x\right)}{\partial x}+\frac{\partial\left(u_y A_y\right)}{\partial y}+\frac{\partial\left(u_z A_z\right)}{\partial z}=0 \quad (1\text{-}1)$$

Type: u_x, u_y, u_z respectively, in x, y, z fluid, fluid velocity component in the Z direction

ρ the density of fluid

A_x, A_y, A_z the fluid in the x, y, z direction of the flow area fraction

2) The momentum equation

$$\left.\begin{aligned}
\frac{\partial u_x}{\partial t}+\frac{1}{V_F}\left(uA_x\frac{\partial u_x}{\partial x}+uA_y\frac{\partial u_x}{\partial y}+uA_z\frac{\partial u_x}{\partial z}\right)=-\frac{1}{\rho}\frac{\partial p}{\partial x}+G_x+f_x\\
\frac{\partial u_y}{\partial t}+\frac{1}{V_F}\left(uA_x\frac{\partial u_y}{\partial x}+uA_y\frac{\partial u_y}{\partial y}+uA_z\frac{\partial u_y}{\partial z}\right)=-\frac{1}{\rho}\frac{\partial p}{\partial y}+G_y+f_y\\
\frac{\partial u_z}{\partial t}+\frac{1}{V_F}\left(uA_x\frac{\partial u_z}{\partial x}+uA_y\frac{\partial u_z}{\partial y}+uA_z\frac{\partial u_z}{\partial z}\right)=-\frac{1}{\rho}\frac{\partial p}{\partial z}+G_z+f_z
\end{aligned}\right\} \tag{2-2}$$

Type: V_F is the volume fraction of liquid

G_x, G_y, G_z is the acceleration of gravity, respectively, in the x, y, z direction of the component

f_x, f_y, f_z is the viscous force, acceleration, respectively in x, y, z direction of the component

So:

$$\begin{aligned}
\tau_{xx}&=-2\mu\left[\frac{\partial u_x}{\partial x}-\frac{1}{3}\left(\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}\right)\right]\\
\tau_{yy}&=-2\mu\left[\frac{\partial u_y}{\partial y}-\frac{1}{3}\left(\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}\right)\right]\\
\tau_{zz}&=-2\mu\left[\frac{\partial u_z}{\partial z}-\frac{1}{3}\left(\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}\right)\right]\\
\tau_{xy}&=\tau_{yx}=-\mu\left(\frac{\partial u_y}{\partial x}+\frac{\partial u_x}{\partial y}\right)\\
\tau_{xz}&=\tau_{zx}=-\mu\left(\frac{\partial u_x}{\partial z}+\frac{\partial u_z}{\partial x}\right)\\
\tau_{yz}&=\tau_{zy}=-\mu\left(\frac{\partial u_y}{\partial z}+\frac{\partial u_z}{\partial y}\right)
\end{aligned} \tag{2-3}$$

Type: μ is dynamic viscosity coefficient

Turbulence model

The fluid turbulence is mainly in the form of a flow from a steady state in the absence of rules transform into a stable state, when the fluid flow of each fluid particle because of inertia, the irregular flow.

The main characteristics of turbulence model is to model in the calculation of the model, the physical aspects of size similar to the infinite, and the use of nonlinear analysis in mathematics, so in the actual calculation and computer simulation, it is difficult to solve the problem of turbulence model. In fluid mechanics analysis software, the simplified turbulent flow model is used to replace the calculation.

There are several kinds of turbulence model, the computational fluid dynamics software in general such as Er Fangcheng $k-\varepsilon$, RNG $k-\varepsilon$ [5]etc.. According to the need to establish the model of this paper can be seen, the simulation of waves in the wave flume wall will and force, and the wave flume model would produce a certain deformation, so the simulation in this paper requires the use of RNG $k-\varepsilon$ model.

VOF free surface tracking method

In the simulation of computational fluid mechanics, when the free surface needs to carry on the analysis, this is a very important part in the simulation process. Now in the fluid dynamics simulation software on the free surface are generally used to track the free surface VOF. The scholars of VOF method of continuous improvement, the VOF method is simple but accurate calculation, can effectively deal with the complex free surface.

VOF method, first of all need to calculate the regional division, the division in each unit within the definition of a function of volume of fluid F. F is expressed as the percentage of fluid volume and the volume of the unit cell[6]. If the fluid filled F=1, unit; if the unit does not have any fluid, F=0. While the liquid free surface unit, at least 0<F<1 and connected to the unit has a unit without any fluid.

In Flow-3D, function F should meet the following equation:

$$\frac{\partial F}{\partial t}+\frac{1}{VF}\left[\frac{\partial\left(FA_x u_x\right)}{\partial x}+\frac{\partial\left(FA_y u_y\right)}{\partial y}+\frac{\partial\left(FA_z u_z\right)}{\partial z}\right]=0 \qquad (2\text{-}4)$$

The building of 3D model

Create a new work space in computational fluid dynamics simulation software flow-3d, and then building a new space simulation in the wok space which used to create 3d wave -current model.

The building of wave current

In this paper, the size of wave current is length 80m, width 6m, height 20m. The wave current was established in the new simulation.

1) boundary conditions

Left end of 3d wave-current is set to the entrance of the waves, boundary, boundary conditions are set as wave type choice of stokes wave height is 1 m, 15 m water depth, cycle for 4s.Set in the front and back sides, of the 3d wave-current for the symmetric boundary, avoid waves spread to wall before and after the reflection, impact wave propagation. When set the symmetrical boundary, flow and fluid shear stress is zero. Using the fluid simulation software of Flow-3d symmetric boundary can more vividly simulate the fluid Flow, and makes the calculation greatly decreased.3d tank bottom is not to penetrate, so set as wall boundary. And above the sink is set as symmetrical boundary. The right side of the tank is set to the flow boundary. The flow boundary form can prevent wave after the wall reflection, and the impact wave fluctuations, lead to inaccurate results. Due to the length of the tank is enough and the right set of outflow boundary wave function to a certain extent, so little waves reflected back on the right wall.

2) Meshing

By known sea water depth of 15 meters, so the setting depth of 15 m, as shown in figure to meshing the model set the depth of a numerical wave-current is 8 meters, after dividing the grid here is as follows.

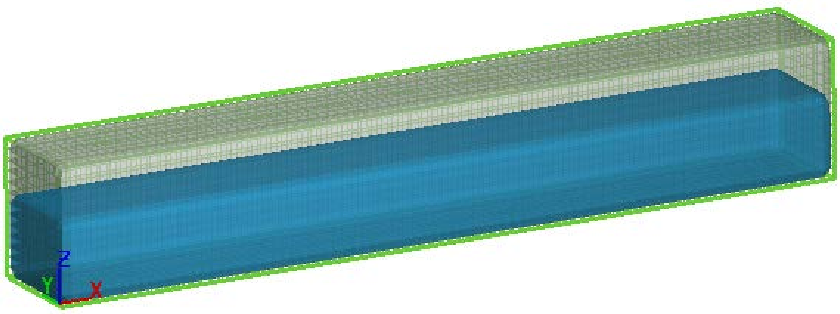


Fig.2-1 Three dimensional wave-current mesh

3) The solver the parameter setting and simulation

Because this article of the floating body wave energy device is to absorb the wave energy by up and down, so just to force analysis of the model of the z axis, as shown in figure 2-1, set the z axis pressure to solving area by the pressure. Figure 2-1, and based on the actual situation to initialize Settings, set for static surface wave, and the waves are not set in motion, so the velocity is zero.

According to the request of model setting, set to RNG model.

Settings for the solution, VOF setting calculation step length is 0.2s, 40s iterative calculation. After the settlement, the result was extracted from the need analysis of the related data and charts. The extract is wave graph, as shown in figure 4-5, and figure 4-6 and 4-7 is the wave of different time.

As can be seen from the figure, the flume and wave are consistent with the required.

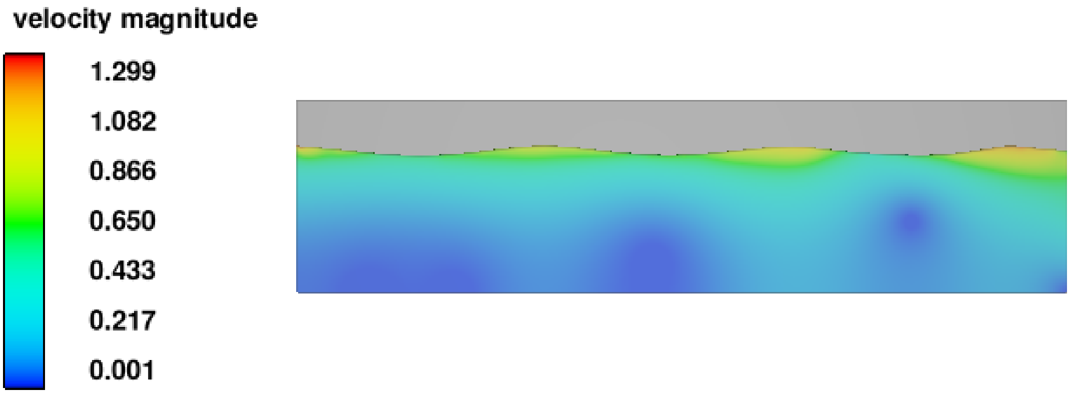


Fig.2-2 wave vector when t=28 Seconds

The simulation of floating body

1) The structure size of floating body

In this paper, the floating body shape is approximate with the sphere cylinder and a semi sphere body, the specific model and size as shown in figure 3-1.

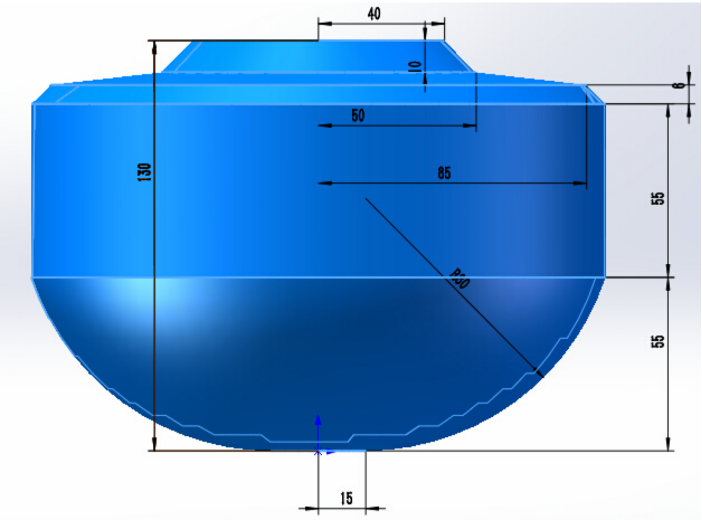


Fig.2-3 The structure diagram of floating body

The floating body into the water tank in the working space, and the floating body is arranged on the left end of the flume is 25 m, depth of submerged floating body is 0.5m.

2) Modeling and Simulation

The floating body in 3D water tank, due to the division of model change is to re mesh the model. The regional variation of wave surface and the floating body and the wave phase contact is relatively large, need to focus on the free surface of the liquid is encrypted on the grid, and the use of nested grid in the floating around, make the results more intuitive and accurate. The model mesh as shown in Figure 2-4, the total grid number is 808952. Because the output is simulated in Flow-3D and the results of the file size is relatively large, so the simulation is required to ensure that the simulation model of the disk in a space, in order to ensure the successful completion of the simulation model.

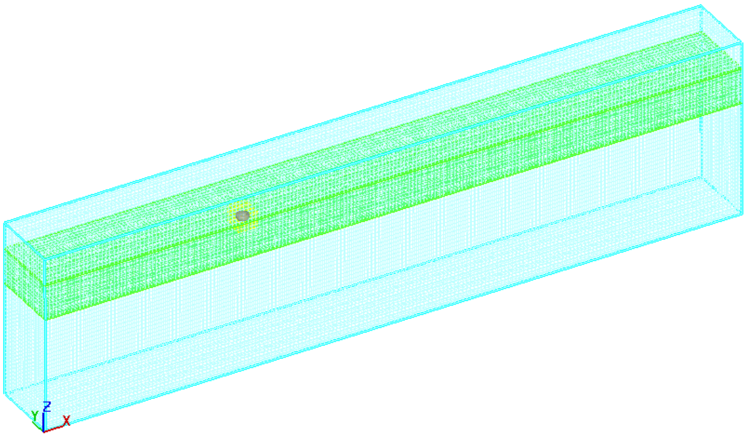


Fig.2-4 Model meshing

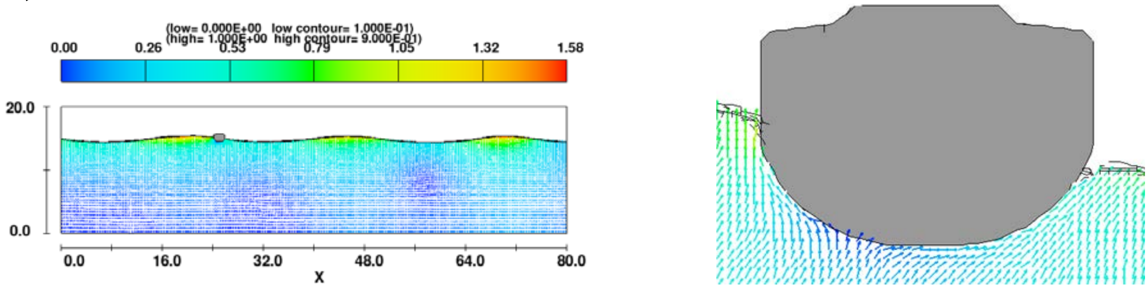
Then the model has been established for 30s simulation calculation. After completion of the calculation, the required data analysis can be selected.

Simulation analysis of floating body

Flow field analysis of floating body

The selection of 3D tank y=0 plane along the face direction, flow field analysis of view of floating body. Read the flow field of a stable period, the floating body vector graph mesh area enlargement, for easy viewing. Analyzed by vector amplification encryption grid interaction of water waves and floating, floating body changes the flow field around the situation.

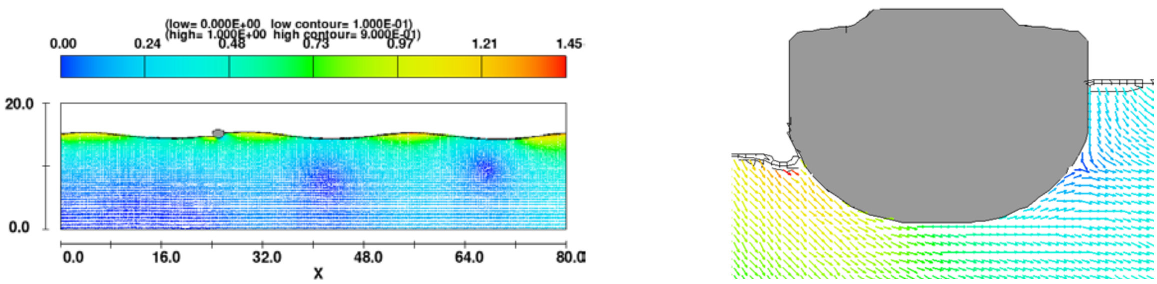
As shown, when the floating body is moving, vectors near the nested grid flow field enlargement are shown from Figure 3-1 to figure 3-5, in a periodic motion in t=23s, t=24.6s respectively, t=25.6s, t=30.6s, t=31s moment.



（a） （b）

Fig.3-1 The flow chart of the floating body when t=23s

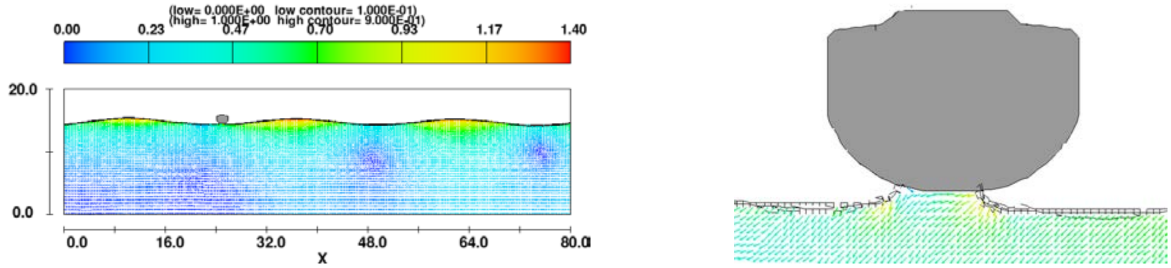
From the 3-1 vectors can be seen in the inset, at t=27s level, the left is higher than the right side of the floating body, and the level of vector direction is to the right of the direction of the wave propagation in the right. Also in the upward floating, floating body under the direction of the vector is upward, indicating the floating body in the waves gradually begins to move upward.



（a） （b）

Fig. 3-2 The flow chart of the floating body when t=24.6s

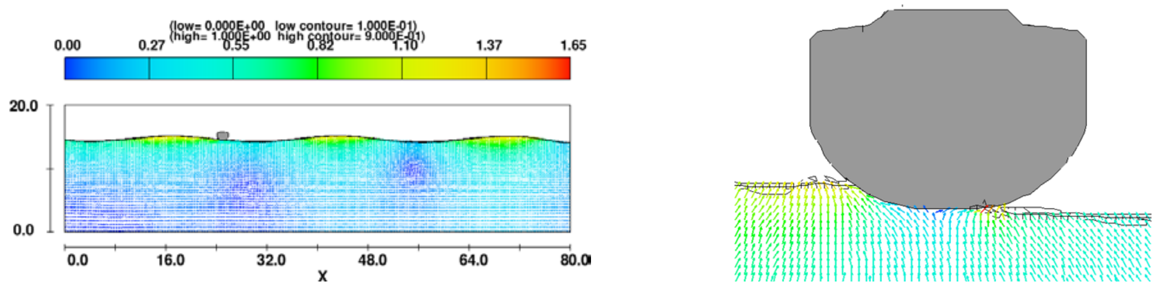
In Figure 3-3, the floating body on the right side of the liquid level rises, the left side of the liquid level drops, the floating body force is larger than the right. On both sides of the floating body and the vector turned down, the floating body to continue in 5-6 downward movement and speed ratio of big now.



（a）　　　　　　　　　　　　　　　　　　　　（b）

Fig. 3-3 The flow chart of the floating body when t=25.6s

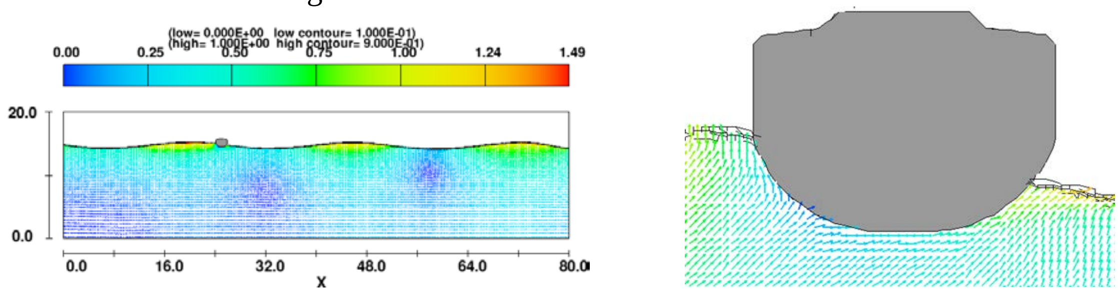
At this time, the wave trough has reached below the floating body, floating body close to being in the valley, in a state of relative balance.



（a）　　　　　　　　　　　　　　　　　　　　（b）

Fig. 3-4 The flow chart of the floating body when t=26.6s

The wave on the right side is coming again and another wave is passing over, the surface on the left side is higher than on the right side again. Floating body at the trough of wave force on a receipt to the upward movement began to overcome gravity. There is a little disorder below the floating body because the wave is coming.



（a）　　　　　　　　　　　　　　　　　　　　（b）

Fig. 3-5 The flow chart of the floating body when t=27s

Figure 3-6 is a cycle, the wave to reach the 3-1 position, the floating body to continue upward movement, to start the next cycle is repeated on a cycle of movement.

The pressure on the floating body

According to the simulation results of fluid simulation software Flow-3D, the interaction between the output wave and floating body results from the picture, you can see the visual changes in different time after the wave buoy.

The design of the hydraulic system of floating wave power device is based on the floating body, only along the vertical direction movement to absorb wave energy, so force of the floating body in the vertical direction is researched, as shown in Figure 3-7 is the floating body is in vertical direction of the force.

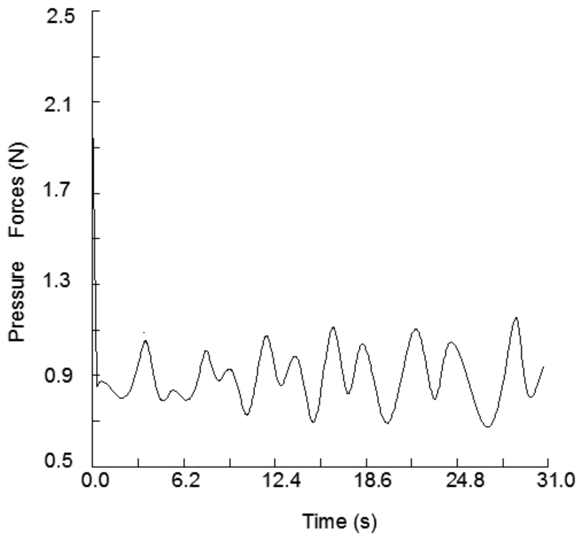


Fig. 3-6 The vertical direction of the floating body force

The up and down driving forces from the wave motion make the floating body move. Due to the wave instability caused by the floating body, the stress is relatively unstable.

It can be seen from the chart, the floating body movement to the highest point, the minimum force of the floating body in vertical direction, and then the floating body effect by its own gravity downward movement; when the floating body in a balanced position, force of floating body in vertical direction is relatively smaller than the force at the highest point; when the motion to the lowest point, the force of floating body vertically into the largest, the vertical force to overcome the gravity of a floating body upward movement. Objects in the vertical direction by the force changes with apparent versus time curve as steep peaks, troughs wide shape.

Conclusion

With the continuous development of wave power device, the floating body movement in waves is very important. Due to the fluid simulation is not only a good simulation model, need a lot of results, also can save the time. Therefore this paper has designed by simulating the floating body, through the analysis of the stress of the floating body designed found floating body is suitable for wave power, designed by the movement of the floating body conform to the normal situation, and can be a very good absorbing wave energy, for subsequent energy conversion, etc.

References

[1] Yin yao, Tomiji Watabe. The comprehensive utilization of ocean wave energy [M]. Shanghai science and technology publishing house, 2011.

[2] The People's Republic of China state development planning commission basic industries development. China's new energy and renewable energy, 1999 white paper [M]. China plans to press, 2000:1-20.

[3] Zhou Zhenggui. Computational fluid mechanics basic theory and practical application [M]. Southeast university press, 2008.1 3.

[4] Yuan-lin li. Wave theory and wave load [M]. South China university of technology press, 1994.186 187.

[5] NAMKOONG K,CHOI H G,YOO J Y.Computation of dynamic Fluid-structure interaction intwo-dimensional laminar flows using combined formulation.Journal of Fluids and Structures, 2005.

[6] Yong-xue wang. VOF method da straight in front of the wall building wave breaking process [J]. Progress in natural science, state key laboratory of communications, 1993.3 (6) : 553-559.