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Simulations of Irregular Waves Based on CFD Method

Guangjian Li*, **Yuanyuan Xu**

Logistics engineering college, Shanghai Maritime University, Shanghai 201306, China
**Corresponding Author*

ABSTRACT. *Material transportation and replenishment is the most basic way of offshore operation, and sea condition is the most important factor to determine the offshore operation. Therefore, it is very important to study the wave under different sea conditions for the operation of marine vessels. In this paper, the numerical flume is taken as the research object, and the irregular waves are produced by using the Computational Fluid Dynamics method on the FLUENT platform. And then, the irregular waves are classified by comparing with the standard of wave classification, which lays a foundation for the design of the ship wave compensation control system under the irregular waves.*

KEYWORDS: *FLUENT, Numerical Flume, the grade of sea state, Irregular wave*

1. Introduction

Sea waves are the most common physical phenomenon in the ocean, which refers to the periodic fluctuations of the water-air interface on the ocean. Sea waves are an important factor affecting the safety of ships' navigation [1]. In the marine industry chain, offshore platform and ships are the most important production and transportation tools, and the marine material supply and cargo transportation are the most basic operations of marine production. When a ship is sailing on the sea, it will swing and heave irregularly with the wind, wave and current. In serious cases, it will lead to the ship's motion out of control and easy to cause accidents [2]. Therefore, it is of great significance to classify the sea wave grades for the study of ship navigation under sea waves. The classification of sea wave levels is shown in Table 1, which Accords to the article "The Formation of Ocean Waves and the Levels of Ocean Waves", Among them: $H_{1/3}$ is the effective wave height, that is, the wave heights in the continuous record of the waves, arranged from large to small, and the average value of the first third of the total wave heights [2].

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Table 1 The wave classification table

Wave level	Wave height	Name
0	0	No waves
1	$H_{1/3}$<0.1	Smooth sea
2	0.1≤$H_{1/3}$<0.5	Small waves
3	0.5≤$H_{1/3}$<1.25	Slight waves
4	1.25≤$H_{1/3}$<2.5	Medium waves
5	2.5≤$H_{1/3}$<4.0	Rough sea
6	4.0≤$H_{1/3}$<6.0	Large waves
7	6.0≤$H_{1/3}$<9.0	High sea
8	9.0≤$H_{1/3}$<14.0	Raging waves
9	9.0≤$H_{1/3}$<14.0	Angry waves

In order to reduce the impact of sea waves on ship operation as much as possible, scholars at home and abroad have done some research in related fields, Among them, He Ping studied the active wave compensation control system [3]; Liao Yong has designed and studied the wave compensation boat lifting system, and proposed to replace the actual wave with regular sine wave to study the wave interference on ships [4]; Li Wenzhong studied the wave compensation system based on multi-sensor [5]. These studies are based on the assumption that sea waves are regular. However, the paper " Research progress of offshore wave " puts forward that the height of sea waves are different at any time, which seems to be irregular and has obvious randomness. That is to say, sea wave is a typical irregular wave [6]. Therefore, when designing a ship's wave compensation control system, it is necessary to create irregular waves similar to real sea conditions, and to study the system compensation control technology under such fluctuations.

Because the real sea wave data is difficult to be measured, the simplest way to get the wave data is to use wave generation. There are two main wave generation methods: physical wave generation and numerical wave generation. Physical wave generation is to use wave maker in wave tank to create wave field which matches the actual environment of ocean engineering in terms of mechanical and statistical characteristics, so as to ensure the accuracy and reliability of model test results [7], the segmented wave maker was developed by Sogreah Experimental Institute of France in 1950. The multi-stage wave maker is arranged in parallel to form oblique regular waves. The latter is a kind of fluid dynamics simulation program based on computer, which can simulate the free surface movement under the action of gravity in a bounded area in real time, and simulate the various wavelengths created by physical wave maker realistically. Compared with the physical wave making method, numerical wave making technology has the advantages of low cost, easy to use, easy to transform and accurate measurement. In this regard, Li Hongwei of Harbin Engineering University has studied and applied numerical wave making [7], which not only provides some theoretical knowledge of numerical wave making, but also integrates these theoretical knowledge with computational fluid dynamics (CFD) technology. CFD technology overcomes the shortcomings of traditional theoretical

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analysis method and simple experimental test method, realizes a specific calculation on the computer, and can vividly reproduce the flow situation [8]. Therefore, CFD method has been widely studied and applied.

In this paper, from the perspective of numerical simulation, by using the push plate method to make the irregular water waves which taking the numerical tank as the research object and relying on the computational CFD method with the help of fluent platform.

2. Mathematical model of numerical wave generation

2.1 The basic model of CFD

The physical laws followed by fluid flow are the main basis for establishing the basic equations of fluid motion [9]. CFD can be regarded as the numerical simulation of flow under the control of the basic flow equations (mass conservation equation, momentum conservation equation and energy conservation equation). Through this numerical simulation, the basic physical quantities of each position in the complex flow field can be obtained. The wave studied in this paper belongs to incompressible viscous fluid, and the research content basically does not involve the dissipation and loss of heat, so only the mass conservation equation and momentum conservation equation are considered. The concrete expressions of the three equations are as follows:

$$\frac{\partial \rho}{\partial t} = div\left(pu\right) = 0 \tag{1}$$

$$\begin{aligned} \frac{\partial(\rho u)}{\partial t} &= div\left(puu\right) = div\left(\mu gradu\right) - \frac{\partial \rho}{\partial x} + S_u \\ \frac{\partial(\rho v)}{\partial t} &= div\left(pvu\right) = div\left(\mu gradv\right) - \frac{\partial \rho}{\partial y} + S_v \\ \frac{\partial(\rho w)}{\partial t} &= div\left(pwu\right) = div\left(\mu gradw\right) - \frac{\partial \rho}{\partial z} + S_w \end{aligned} \tag{2}$$

$$\frac{\partial(\rho T)}{\partial t} = div\left(puT\right) = div\left(\frac{k}{c_P} gradT\right) + S_T \tag{3}$$

Where: ρ is density; t is time; u is the velocity vector; S_u、S_v、S_w are the generalized source terms of the momentum conservation equation, u, v and w are the components of velocity vector u in x, y, z directions respectively; μ is the dynamic viscosity; λ is the second viscosity; T is the temperature; k is the fluid heat transfer coefficient; c_p is the specific heat capacity; S_T is viscous heat dissipation. For incompressible fluid, the heat exchange rate is small and negligible.

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2.2 Free surface treatment method

In the simulation of wave motion, there are only two phases of air and water on the interface, so we can use the VOF model to track the free surface flow. The basic idea of the VOF model is to determine the free surface by studying the volume ratio function f of the fluid in the grid cell and track the change of the fluid: if $f = 1$, it means that the cell is all occupied by the specified phase flow; if $f = 0$, the unit is an unspecified phase flow unit; when $0 < f < 1$, the unit is called an interface unit [10]. Assuming any point (x, y) in the flow field, define the function $f(x, y, t)$ as follows:

$$f(x,y,t)=\begin{cases}1 & \text{There are fluid particles of this phase at x and y points}\\ 0 & \text{There are no particles of this phase at x and y}\end{cases} \tag{4}$$

The conservative transfer equation is expressed as follows:

$$\frac{\partial f}{\partial t}+\frac{\partial uf}{\partial x}+\frac{\partial vf}{\partial y}=0 \tag{5}$$

2.3 Principle of wave making with push plate

Push plate wave making is to simulate the forced vibration of solid boundary as the disturbance source of wave flume, so as to generate waves. Its principle is to force the horizontal velocity of water point movement to achieve the purpose of simulating corresponding wave [11].

$$u(t)=\frac{X_0}{2}\omega\cos\cos\omega t \tag{6}$$

The wave surface equation of the wave:

$$\eta(x,t)=\frac{2X_0\omega^2\cosh kd\cdot\sinh kd}{kg(\sinh 2kd+2kd)}\cos(kx-\omega t) \tag{7}$$

Where: X_0 is the stroke of wave maker plate, K is wave number, $K = 2\pi/l$, D is water depth.

3. CFD model and simulation result analysis of push plate wave making

3.1 The calculation model of the push plate wave making

The two-dimensional numerical pool model adopted in this paper is 10 m long and 2 m wide, and the water surface position is 0.5 m. Among them, the left side of the numerical water tank is the push plate, the right side is the side wall of the water

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tank, the bottom is the bottom of the water tank, and the upper part is the open area connected with air, and the coordinate system is established as shown in Figure 1.

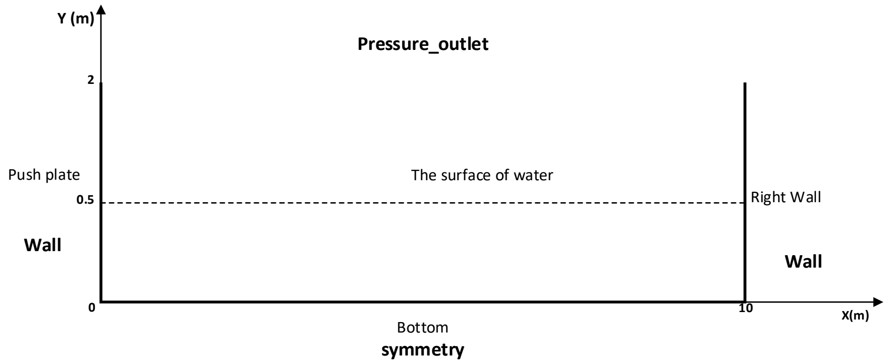

Figure. 1 Numerical flume calculation model

For this numerical pool, GAMBIT software is used for grid division. The entire calculation area uses a quadrilateral grid, and the height of each cell is 0.005 m.

Table 2 Boundary condition setting table

Name	Bottom of sink	Push plate	Right wall	Upperside
Boundary condition	Symmetry	Wall(moving boundary)	Wall	Pressure_outlet

3.2 FLUENT simulation strategy with periodic push board movement

For the simulation strategy, this paper uses the transient profile file and FLUENT to carry out the linkage simulation; that is, the profile file is used to specify the total time length of the specified motion boundary (push plate) and the corresponding speed size and direction at each time. At the same time, the phase interface is monitored at three positions X=3m and X=7m (respectively corresponding to the front side, the center of gravity side and the rear side of the hull studied later) ,which is the height of the waves.

After many simulation tests, in order to avoid the problem of simulation caused by the too high setting speed of the push plate, a large amount of water splashed out of the numerical pool during the simulation process, which would affect the subsequent data processing and analysis results, the speed of each time of pushing plate was set within ± 3m / s, as shown in Fig. 2.

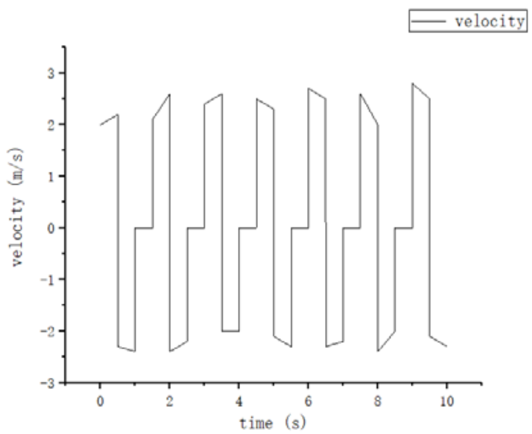

Figure. 2 Non periodic velocity diagram of push plate with time

3.3 Analysis of simulation results

As shown in Fig. 3, the volume fraction distribution nephogram of water and gas two phases is shown when step = 2280.

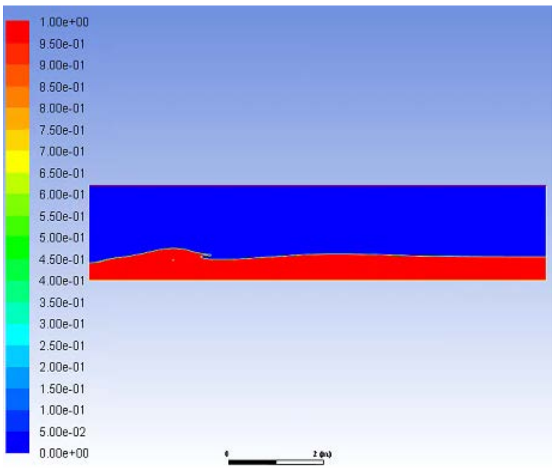

Figure. 3 Nephogram of water and gas two-phase volume fraction distribution at step=2280

The simulation results are shown in Figure. 4 ~ Figure. 6. Figure 4 is the curve of the wave height at the monitoring position X=3m over time; Figure 5 and 6 are the curve of the wave height at the monitoring position X=5m and X=7m over time.

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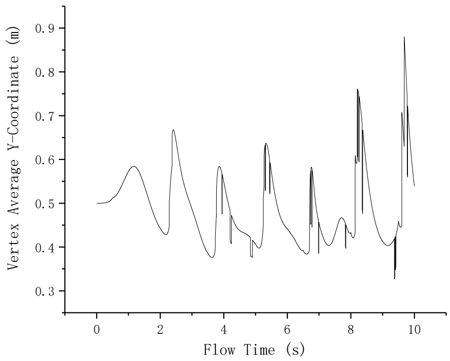

Figure. 4 Wave displacement curve with time at x = 3m

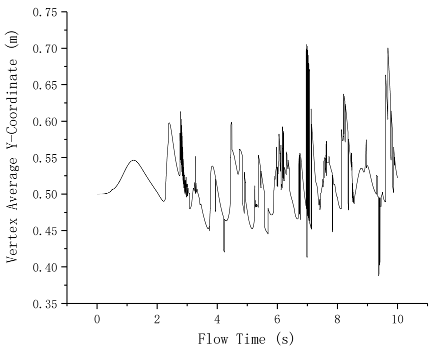

Figure. 5 Wave displacement curve with time at x = 5m

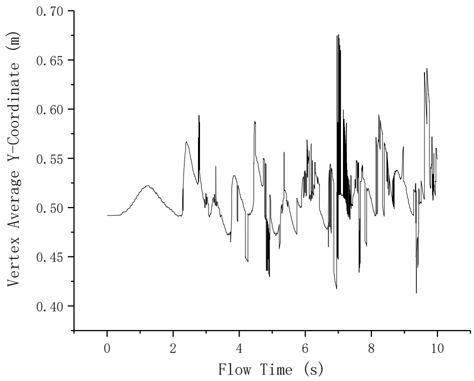

Figure. 6 Wave displacement curve with time at x = 7m

According to the analysis of Figures 4, 5, 6 and tables 3, 4, 5 the expected irregular waves can be obtained at all positions in the numerical flume under the aperiodic push plate wave making; compared with the free surface, the wave crest at x = 3m increases by 27.6%; the crest at X=5m increased by 14.89%;the peak at x = 7m increases by 12.7%. Under the design of the push plate wave making, the irregular wave obtained as the monitoring point moves away from the push plate, the wave height fluctuation becomes smaller and the number of wave crests increases : This is because the farther away from the push plate, the less affected by the speed of the push plate, but at the same time, the wave reflected from the right wall of the water tank will overlap with the wave generated by the push plate, resulting in the wave height fluctuation at the position far away from the push plate becoming smaller and smaller, and the number of wave peaks increasing.

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Table 3 Data of wave displacement with time at x = 3m

Time/s	Displacement/m	Time/s	Displacement/m
1.1	0.589	5.3	0.638
2.4	0.668	6.7	0.579
3.8	0.588	8.2	0.763

Table 4 Data of wave displacement with time at x = 5m

Time/s	Displacement/m	Time/s	Displacement/m	Time/s	Displacement/m
1.1	0.547	4.40	0.561	6.97	0.703
2.3	0.598	4.76	0.561	7.67	0.549
2.7	0.603	5.32	0.552	8.16	0.628
3.2	0.517	6.09	0.577	8.94	0.545
3.8	0.540	6.72	0.555		

Table 5 Data of wave displacement with time at x = 7m

Time/s	Displacement/m	Time/s	Displacement/m	Time/s	Displacement/m
1.2	0.522	4.4	0.574	7.6	0.542
2.4	0.565	5.3	0.517	8.2	0.593
2.8	0.583	6.0	0.555	8.8	0.541
3.2	0.509	6.7	0.543	9.6	0.636
3.8	0.533	7.0	0.669		

4. Analysis of analogy wave grade

Generally speaking, the classification of wave grade is determined by the effective wave height of the wave. The specific analysis is shown in Table 6- table 8. The effective wave heights in the table are calculated according to the horizontal plane.

Table 6 Data of wave height with time at x = 3m

Time/s	Displacement/m	Time/s	Displacement/m
1.1	0.089	5.3	0.138
2.4	0.168	6.7	0.079
3.8	0.088	8.2	0.263

Table 7 Data of wave height with time at x = 5m

Time/s	Displacement/m	Time/s	Displacement/m	Time/s	Displacement/m
1.1	0.047	4.4	0.061	6.9	0.203
2.3	0.098	4.7	0.061	7.6	0.049
2.7	0.103	5.3	0.052	8.1	0.129
3.2	0.017	6.1	0.077	8.9	0.045
3.8	0.040	6.7	0.055		

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Table 8 Data of wave height with time at x = 7m

Time/s	Displacement/m	Time/s	Displacement/m	Time/s	Displacement/m
1.2	0.022	4.4	0.074	7.6	0.042
2.4	0.065	5.3	0.017	8.2	0.093
2.8	0.083	6.0	0.055	8.8	0.041
3.2	0.009	6.7	0.043	9.6	0.136
3.8	0.033	7.0	0.169		

1) Monitoring position x = 3m, the corresponding displacement is obtained as shown in Table 6. According to the solution requirements of effective wave height, $H_{\frac{1}{3}}$ = 0.214m is obtained.

2) Monitoring position x =5m, the corresponding displacement is obtained as shown in Table 7. According to the solution requirements of effective wave height, $H_{\frac{1}{3}}$= 0.122m is obtained.

3) Monitoring position x = 7m, the corresponding displacement is obtained as shown in Table 8. According to the solution requirements of effective wave height, $H_{\frac{1}{3}}$= 0.111m is obtained.

Therefore, table 9 can be obtained from the above calculation data and combined with the sea wave judgment criteria.

Table 9 Table of classification results of analogy sea wave

Position	$H_{1/3}$	Name	Analogy of wave grade
X=3m	0.214	Small waves	2
X=5m	0.122	Small waves	2
X=7m	0.111	Small waves, close to micro waves	2(Closer to 1)

According to the comprehensive wave and wave analogy data table, under the current pushing plate speed, the effective wave height obtained at the position of x = 3m and x=5m can be compared with the small wave with the wave grade of grade 2; the effective wave height obtained at the position of x = 7m is more close to the micro wave with the wave grade of 1, As the monitoring position is gradually larger from the position of the push plate, the wave height of the obtained water wave gradually becomes smaller. At the same time, it can be concluded that by increasing the speed of the push plate within a certain range, a higher level of waves can be obtained.

5. Conclusion

With the continuous development of marine operations, it is very important to study the influence of ocean waves on research ships in different sea conditions. In

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this paper, with the fluent platform, the numerical pool is taken as the research object, and the irregular water wave is obtained through the corresponding speed experiment simulation of the push plate. Combined with the classification standard of wave grade, the corresponding wave grade of irregular waves under wave making is obtained by analogy. The specific research results are as follows:

1) Under the non-periodic push plate movement, irregular water waves can be obtained at different positions of the tank; Three positions are monitored in this paper which in the center of gravity side and the rear side of the hull. At x = 3m, x=5m and x = 7m, the wave crest increments of these three points are 27.6%, 14.89% and 12.7%, respectively. It can be seen that with the distance between the monitoring position and the pushing plate, the influence of the pushing plate speed becomes smaller and smaller, and the wave peak increment obtained also decreases.

2) The effective wave heights obtained from the three locations monitored in this paper are: 0.214m (x=3m), 0.122m (x=5m) are similar to that of small wave with wave level 2 and 0.111m (x=7m) as small wave of wave level 2. But, according to Table 1.1, the wave level at x=7m is closer to that of level 1.

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