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A Preliminary Study on Numerical Waves and Its Impact on Horizontal Plate Based on Fluent

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Abstract. Based on the N-S equations for viscous, incompressible fluid and *RNG* $k-\varepsilon$ turbulence model, a two dimensional Numerical Wave Tank is established, utilizing the secondary development function of Fluent software and the *VOF* method. A two-dimensional linear regular wave and a random wave are generated by defining the motion of moving boundary and adding wave absorbing zone at the end of the wave tank. The resulting numerical wave shape agreed well with the theoretical shape. The simulated wave spectrum of random wave keeps the original structure of the target spectrum. The impact of waves on the horizontal plate is simulated referring to the existing physical model test .Compared with the physical and the numerical pressure data of *11* pressure points under the horizontal plate, it is found that the two datas fit well, indicating the effectiveness of *Fluent* in simulating the interaction between waves and structures, which lays a foundation for further exploring the factors that affect the magnitude of the impact pressure on the horizontal plate.

1. Introduction

With the rapid development of the marine economy, it has become a hot topic to explore the generation and evolution of waves and its impact on marine structures. In order to better study the regularity of wave action on marine structures, low cost and repeatable artificial wave-making methods are often used in the research. The artificial simulation of wave-making methods is divided into two parts: physical test and numerical test. Compared with physical model test, the advantages of computer numerical simulation are mainly economic and small scale effect, and it can effectively avoid the influence of sensor on flow field. Therefore, computer numerical method gets more and more scholars' favor.

At present, the research on numerical simulation mainly focuses on the method of wave making and wave absorbing. Liang[1] imitated physical method of paddle wave maker, combined with the *UDF*(User defined Function) and dynamic mesh function of *Fluent* software, simulating the irregular wave preferably. Based on *Fluent* software, a three-dimensional numerical wave flume was established by Lu[2]. Three dimensional stokes waves in three different working conditions were simulated by source function wave-making method in her test, which certified that *Fluent* has a good effect on wave-making. Based on the *N-S* equation of viscous incompressible fluid, Huang[3] established a two dimensional numerical wave flume by using open source *CFD* code *OpenFOAM*. The results showed that regular waves could be effectively made up by *OpenFOAM*. Li[4] simulated linear regular waves, irregular waves, Stokes waves and solitary waves using both paddle and source wave-making method , and compared the advantages and disadvantages of the two methods. Xin[5] defined the motion law of the wave-making board and successfully absorbed the wave at the wave absorbing area by using the macro function of *UDF*. The simulated numerical wave agrees well with the theoretical solution and the boundary element results.

In the field of wave absorbing, Dong[6] proposed a porous media wave absorbing method which can absorb simulated waves effectively, and gave a best combination of wave making and wave elimination. A conserved absorbing method is proposed Hu[7].By comparing the generated surface histories with the theoretical results, it is found that the conserved absorbing method is efficient for regular waves, random waves and nonlinear waves.

It is a very popular trend to add structures in numerical flume to simulate the effect of waves on marine construction in real ocean environment. Using the secondary development function of *Fluent* software, Zheng[8] put up a submerged seawall in the numerical tank, in order to explore the effectiveness of *Fluent* in simulating the interaction between waves and structures. Nonlinear boundary element method was used by Rolf Baarholm[9] to simulate the process of wave impact on the horizontal plate. Using *Fluent* software, Jin[10] established a two-dimensional mathematical model of interaction between regular wave and flat plate structures. By comparing the numerical simulation and experimental results of different working conditions, the field characteristics influenced by the impact process of waves on the structure was obtained, and the relationship between velocity of water point and impact pressure was got too.

Based on the user defined function (*UDF*) of *Fluent* software, this paper used a push-pedal wave-making method to simulate a two-dimensional linear regular wave and a random wave. A horizontal plate was added to the numerical flume to simulate the impact of regular waves on the horizontal plate. By comparing the numerical test data and the physical test data, the reliability of *Fluent* in simulating the interaction between waves and coastal structures is verified.

2. Mathematical Model

The control equation includes the fluid continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}=0 \tag{1}$$

N-S equation:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\upsilon(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2})+g_x+S_x \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\upsilon(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2})+g_y+S_y \tag{3}$$

In the formula, *u, v* is the speed in the direction of *x* and *y*, respectively; g_x , g_y is the acceleration of *x* and *y* direction ,and $g_x=0$, $g_y=-g$; *p* is the fluid pressure; ρ is the density of fluid; υ is the kinematic viscosity of fluid; S_x and S_y are the source term of wave absorbing, which are added only in the wave absorbing region. The expressions are as shown in (4):

$$S_x=\mu(x)\cdot u,\ \ S_y=\mu(x)\cdot v,\ \ \mu(x)=\alpha\frac{(x-x_1)}{\left|x_2-x_1\right|},\ x_1\le x\le x_2 \tag{4}$$

In the formula, $\mu(x)$ is the damping coefficient; α is the empirical parameters; x_1 and x_2 are the starting and terminal coordinates of the wave absorbing region, respectively.

VOF method is used to capture the free surface, and the transport equation of fluid volume function is proposed as follows:

$$\begin{cases}\dfrac{\partial \alpha_q}{\partial t}+\dfrac{\partial(u\alpha_q)}{\partial x}+\dfrac{\partial(v\alpha_q)}{\partial y}=0\\ \displaystyle\sum_{q=1}^{2}\alpha_q=1,(q=1,2)\end{cases} \tag{5}$$

In the formula, α_q is the volume fraction of fluid, defined as the ratio of the volume of a fluid in phase *q* to the volume of the unit. If α_q =1, the unit is filled with *q* phase fluid, if α_q =0, there is no *q* phase fluid in the unit, and if 0< α_q <1, the unit is a interface unit. As the numerical simulation, *q*=1 or 2 represents the air phase and the water phase, respectively.

3. Numerical Simulation

3.1. Geometric Model

Gambit software is used to establish the geometric model, as shown in Figure 1. The size of the numerical flume is *16m×1.2m*. While the depth of water is *0.8m* and the wave absorbing region is *4m* long at the end of the flume. The wave plate is set at the left boundary. Numerical flume mesh generation is shown in Figure 2, and the total grid is about 68900. The size of the grid is *0.05m* in the direction of wave propagation, and the size of the grid at the wave absorbing area is divided by gradual thinning method. Refine the grid at free surface to ensure the accuracy of calculation.

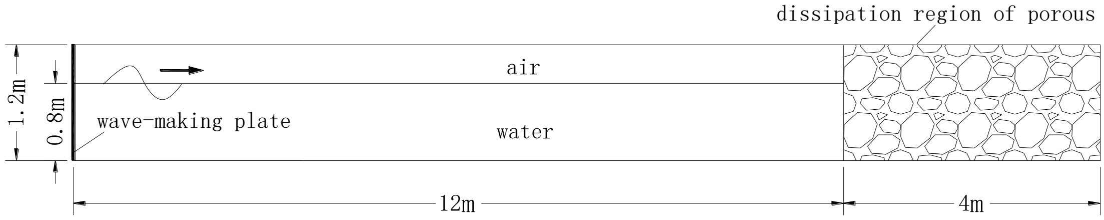

Figure 1. Numerical flume geometric diagram

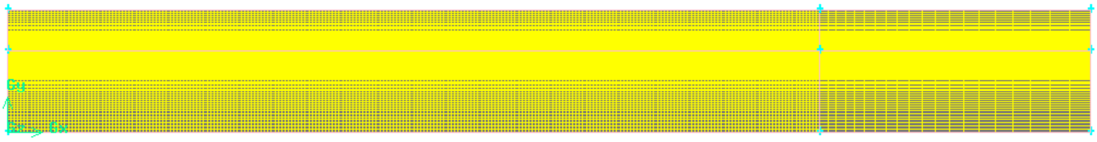

Figure 2. Mesh of numerical flume

3.2. Wave Simulation

The numerical flume is used to simulated regular waves and random waves both. The factors of regular waves are given as follow: wave height *H=0.1m*, periodic *T=1.6s*, depth of water *h=0.8m*, and wave length *L=3.55m*.

The *JONSWAP* spectrum is the target spectrum of simulated random waves. The parameters of *JONSWAP* spectrum are shown as follow: significant wave height *Hs=0.1m*, peak period of spectrum *Tp=1.6s*, depth of water *h=0.8m.*

The motion law of push plate is defined by the *DEFINE_CG_MOTION* macro in *UDF*, and the source item of wave elimination is written through *DEFINE_SOURCE* macro, and finally the macros are imported to *Fluent* through the Define Command Window.

3.3. The Parameter Setting of Fluent

A push plate wave-making method is used to simulate waves, so the left boundary is defined as the dynamic boundary, the top boundary is the pressure inlet boundary, and the rest is the wall boundary. The free surface of water is captured by the *VOF* method, and the *RNG* $k-\varepsilon$ turbulence model is used for turbulence model. The pressure velocity term is calculated by *PISO* algorithm. The layer pattern (*Layering*) is selected to update the grid to realize the motion of the wave-making plate. Time step is *0.005s*, and total calculation time is *50s*.

3.4. Analysis of Calculation Results

The comparison between the theoretical wave duration curve and the simulated wave duration curve of regular wave at one and three times wavelengths are given in Figure 3 and Figure 4 , respectively. As can be seen from Figure 3, the theoretical curve and the simulated curve fit well, the period of simulated wave is basically the same as the theoretical ones, and the phase is almost no deviation. But the wave height is attenuated from Figure 4, and the attenuation degree of wave height increases with the distance of wave propagation. This is mainly due to the fact that the regular waves based on potential flow theory are put forward in the ideal state of irrotational and inviscid, and the numerical wave simulated in this paper takes the effect of viscous and turbulence of water into account.

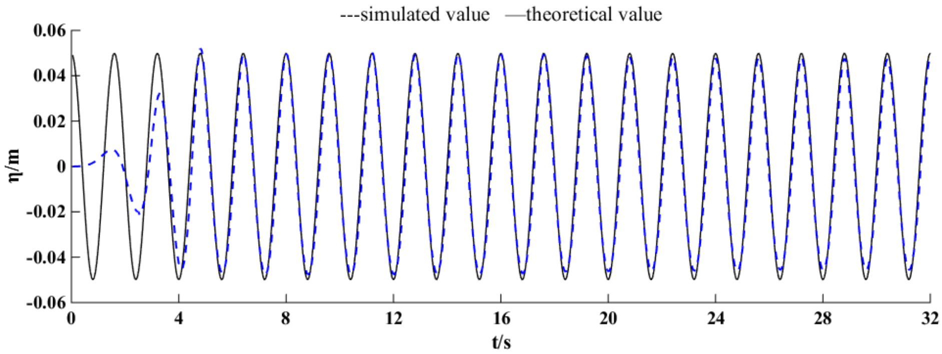

Figure 3. Comparison of theoretical value and simulated value of regular wave at one time wavelength

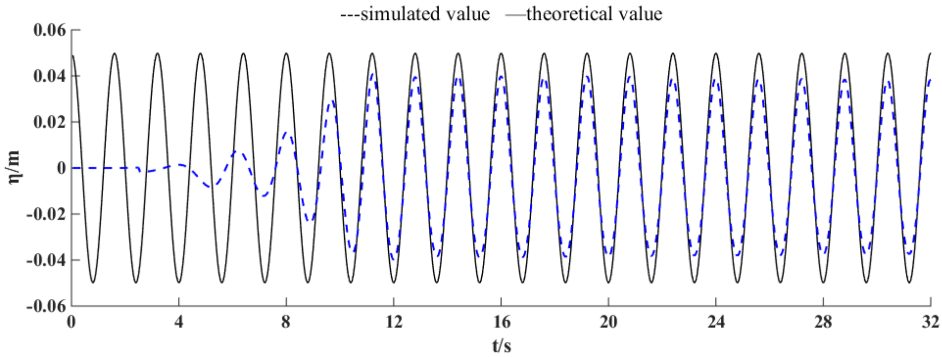

Figure 4. Comparison of theoretical value and simulated value of regular wave at three times wavelengths

The comparison between the theoretical wave duration curve and the simulated wave duration curve of random wave is given in Figure 5. It can be found that the two curves are in good agreement, which shows a good results of *Fluent* in simulating random waves.
The wave duration curve only reflects the external characteristics of the wave, while the wave spectrum can describe its internal structure. The simulated spectrum can be obtained by spectral analysis of waves at the location of 2m.
Comparison between the target value and simulated value of spectral parameters can be seen in Table1. From Table1, we can see the fact that there are little differences between the parameters of simulated and target spectrum.
From Figure 6, we can also get that the simulated wave spectrum keeps the original structure of the target spectrum.

Table 1. Comparison of spectral parameters

	significant wave height	peak period of spectrum

target value	0.1	1.6
simulated value	0.0956	1.587

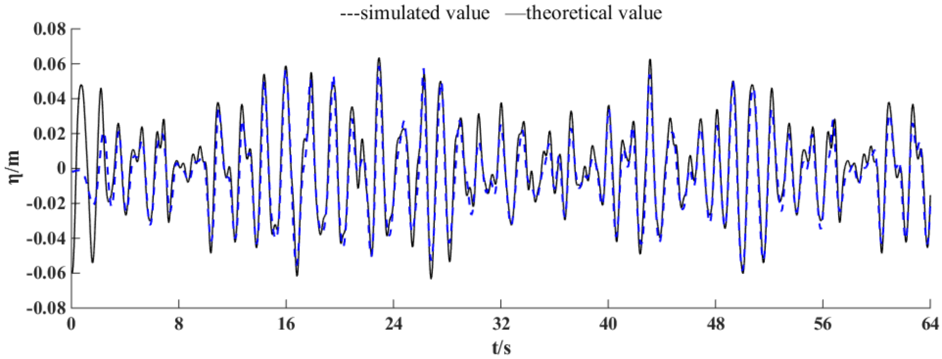

Figure 5. Comparison of theoretical value and simulated value of random wave

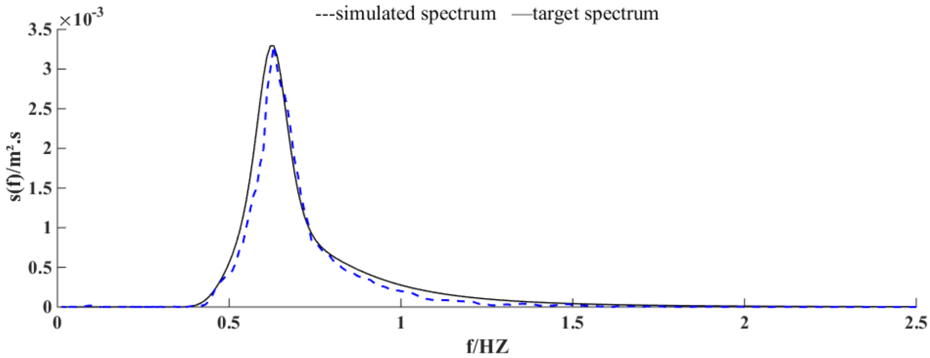

Figure 6. Comparison of target spectrum and simulated spectrum

4. Interaction between Waves and Horizontal Plates

4.1. The Position of the Horizontal Plate and Pressure Measurement Point

Dr. Ren[11] of Dalian University of Technology has done a series of physical model tests on the impact of waves on the horizontal plate. With reference to his physical model test, the geometry of the wave numerical tank and the layout of the horizontal plate are shown in Figure 7. The flume is *16m*×*1.0m*, while the depth of water is *0.6m* and the wave absorbing region is *4m* long at the end of the flume. The center of the horizontal plate is located at *x=8m*.The plate measures *1.0m* long×*0.02m* thickness, and the bottom of the plate is *0.03m* above the free surface.

11 virtual pressure points are arranged at the same distance (*0.09m*) at the bottom of the plate, while the distance between the two end pressure points and the ends of plate both are *0.05m*.

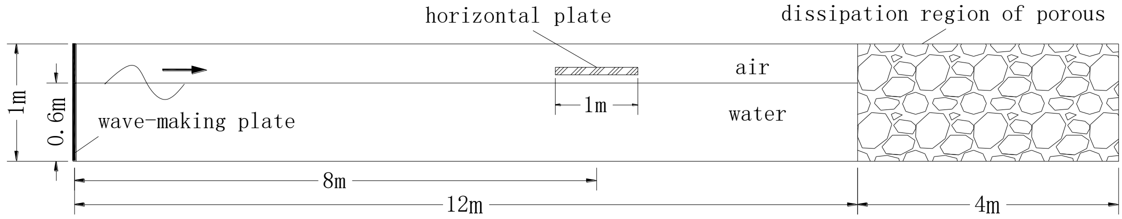

Figure 7. Geometric diagram of numerical flume with horizontal plate

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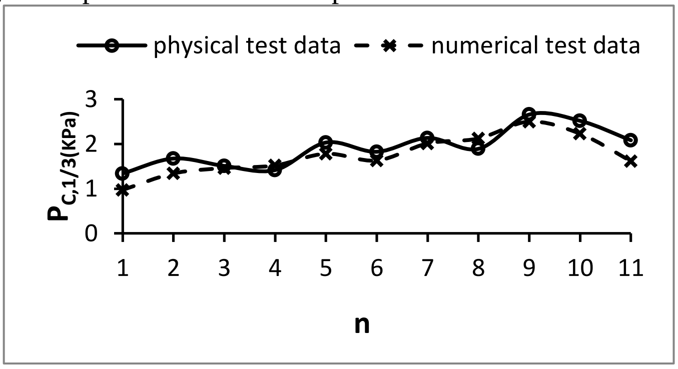
4.2. The Impact of Wave on the Horizontal Plate

Two groups of numerical experiments are carried out according to the difference of the relative plate length. *Case 1:* $L_m/L_1=0.33$ $H=0.1m$ $\Delta h/H=0.03$; *Case 2:* $L_m/L_2=0.47$ $H=0.1m$ $\Delta h/H=0.03$ .In both case, L_m is the length of the plate, L_1 (L_2) is the wavelength of regular waves in *Case1(Case2)*, H is the wave height and Δh is the distance between the bottom of the plate and the free surface. The simulation time of each case is *30* times of wave period, and each period will have a peak pressure (maximum impact pressure). The average value of the pre *1/3* data of the *30* peak pressure of each measurement point is $P_{C,1/3}$ as the characteristic value, and the results are compared with the pressure data of physical test. The diagram is shown in Figure 8.

It can be seen from the graph that under different working conditions, the distribution law of the characteristic pressure along the bottom of plate in the numerical simulation test is approximately the same trend as that obtained from the physical model test, which indicates that *Fluent* has high accuracy in simulating the impact of waves on the plate structure.



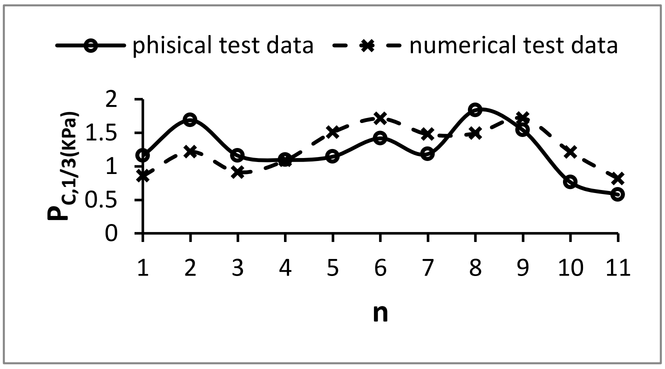


Figure 8. Comparison between characteristic pressure of numerical test data and physical test data at Case1(left) and Case 2(right)

5. Conclusion

Based on the *UDF* function of the *Fluent* software, this paper successfully simulates the regular wave and the random wave. The impact of wave on the horizontal plate is simulated by adding a horizontal plate structure to the numerical tank. Summarize as follow:

(1) In this paper, the *RNG* model and the *VOF* free surface capture method are used to simulate a two-dimensional regular wave and a random wave, and both simulated values are well fitted to the theoretical values. The simulated spectrum keeps the original structure of the target spectrum, and the parameters of simulated spectrum have little difference from target spectrum. The attenuation of wave height reflects the propagation state of real viscous flow in a certain extent.

(2)Compared with the existing physical model test, the impact process of regular waves on a horizontal plate was simulated by *Fluent.* By comparing the characteristic impact pressure values of *11* points under the plate, it is found that the numerical results are of high accuracy. There are some

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shortcomings in this article that need further study, for example: the influence of wave height loss and the disturbance of horizontal plate to wave field are not taken into account in the numerical test.
This paper lays a foundation for further study of the influence factors of the impact of waves on the plate structures.

6. References

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