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Numerical study on the wave force of the metal net under regular waves

C P Chen¹, H F Liu¹, Y N Zheng^{1*}, X M Liu¹ and Y H Fang¹

¹ School of Ocean and Civil Engineering, Dalian Ocean University, Dalian, Liaoning, 116024, China

*Corresponding author's e-mail: zhengyn0506@163.com

Abstract. In this paper, the simulation of the forces on mental net is studied under regular wave. The FEM (Finite Element Method) and the Morison Equation are used in simulating the netting structure and the wave force respectively. Based on the Newmark method in Abaqus, verified by the comparison between the simulation and experimental results, the wave forces under different wave conditions, mesh size and net thread diameter are calculated and analyzed which will afford a reliable foundation for the following research on the metal net cage.

1. Introduction

Currently, the destruction of marine environment is becoming more and more obvious due to traditional near shore cages. Compared with traditional cages, the deep-sea metal cages have the advantages of resistance to wave, flow and corrosion, light adhesion and low pollution, which has become a new breed model with great development potential. However, the study of the metal net under waves is relatively rare to be found. There is significant difference between the fiber net and the metal one in terms of mass, stiffness, surface roughness, and so on. Therefore the corresponding hydrodynamic characters are also different, and then the entire cage system will change in turn. Therefore, in order to have a good understand of the dynamic behavior of the entire metal cage, it is greatly helpful to analyze its hydrodynamic characteristic of the metal netting as the foundation study.

Netting is a basic functional and structural component of net cage, and its hydrodynamic respond under wave and current is very large. Physical model experiment and numerical simulation are used in a large range on the study of the flexible netting. Based on the wave theory, the fluid character and boundary conditions of the wave transmitted from the net was analyzed, and the relationship between the transmission coefficient and the main parameters (net size, wave character, etc) were studied ^[1]. The wave loads on plane nets are studied by numerical model ^[2] and experimental way ^[3] respectively. Based on Abaqus, the hydrodynamic respond of the net-cage under wave and current was simulated using the FEM ^[4,5].

Taking the metal netting as consideration, the drag forces as well as the drag coefficient were studied experimentally. The copper alloy net was discussed with different water permeability ^[6], and the experimental formula ^[7] and the result of fiber net were also referred as comparison ^[8]. The equivalent stiffness was applied to simulate the volume deformation.

In this paper, the numerical simulation combined with physical experiment is used to study the wave force variation under different wave height, mesh size and net diameter which will afford a reliable foundation for the following research on the mental net cage.



2. Descriptions

2.1 Motion equations

For the net mesh, the structural dynamic equilibrium equation can be written as:

$$[m][\ddot{x}] + [c][\dot{x}] + [k][x] = G + F_B + F_D \quad (1)$$

where $[m]$ is the total mass matrix of the nets, $[c]$ is damping matrix from the structural deformations of the nets, $[k]$ is the stiffness matrix of the nets, the right side of the equation is the external loads acting on the structure including the gravity G , the buoyancy force F_B and the wave forces F_D , which can be calculated by Morison Equation in every moment shown as following:

$$F_D = \frac{1}{2} \rho_w C_D D \Delta v |\Delta v| \quad (2)$$

Where ρ_w is water density, D is the thread diameter, Δv is the relative velocity of water particle and net element, C_D is the coefficient. The velocity of water particle in 3 directions can be calculated based on the wave theory.

2.2 Net model

The net is simulated by beam element and the connection between net chains is stimulated by join element, which is shown in Fig.1. The net model is set up by the Standard Model in ABAQUS, and the model is the same as the actual one. Hypermesh is used to mesh the net model with the structural mesh of hexahedron. Take the net with 4mm diameter and 45 mm net size as an example, the element number is 6336.

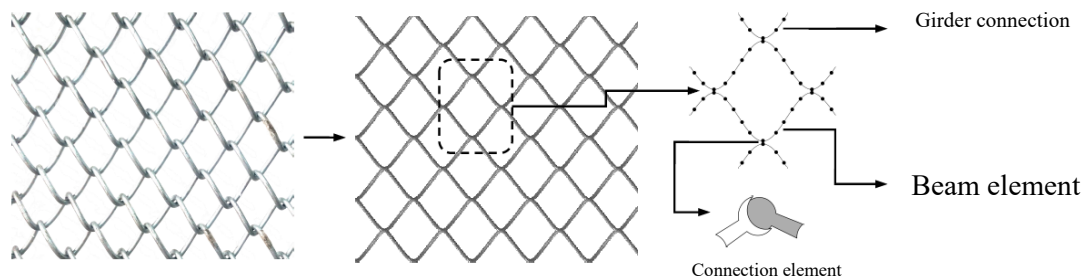


Figure 1. Mesh of the net structure

2.3 Workflow of numerical simulation

Newmark method is used to solve the motion equation, which is a kind of implicit expression and is stable unconditionally. Firstly, the total mass matrix $[m]$, damping matrix $[c]$ and the stiffness matrix $[k]$ are established, the initial displacement x_0 , velocity $\dot{x}_0$ and acceleration $\ddot{x}_0$ are assigned according to the given initial conditions, the time step Δt is selected and the relative parameter and integral constants are calculated. And then the effective loads, the acceleration, the velocity and displacement in each time are calculated which will be set as the given value for the next time $t + \Delta t$. Fig. 2 shows the Workflow of the numerical simulation.

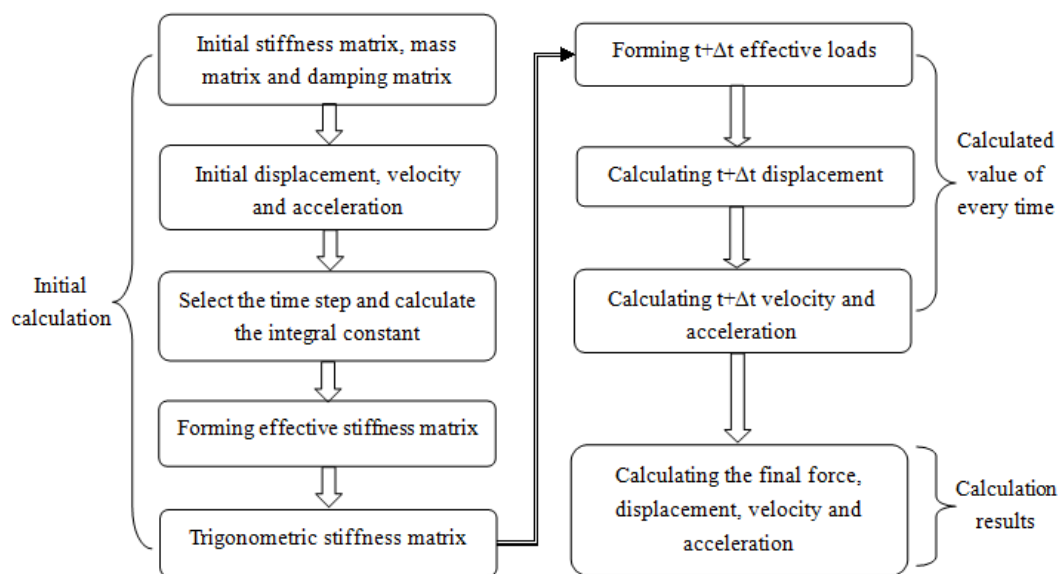


Figure 2. Workflow of the numerical simulation

3. Numerical simulations and experimental validations

The parameters of the metal net showed in Table 1 are designed as different diameter, and size, according to the actual aquaculture conditions.

Table 1. Properties of metal net

Item	Content	Item	Content
Material	copper-zinc alloy	Size of net sheet	80 cm×80 cm
Diameter of thread/ <i>d</i>	2.5 mm;3.2 mm;4.0 mm	Young's modulus	145 Gpa
Mesh size/ <i>m</i>	25 mm;35 mm;45 mm	Poisson ratio of material	0.3

3.1 Introduction of experiment

All the physical model tests in this paper were conducted in the Ship Model Tank of Dalian University of Technology. The size of the tank is 170 m×7 m×4 m. The four sides of the net model were fixed with the iron frame. The tensor and data collection system are set on the top of the frame, which are shown in Fig.3. During the tests, the net sheet submerges under water. The wave height is 0.15 m with 5 different periods (1.0 s, 1.2 s, 1.4 s, 1.6 s and 1.8 s).

3.2 Experimental Validations

Based on the experimental conditions, the forces on net are simulated under different circumstance with five kinds of different wave period. Fig.4 shows the comparison of the calculated forces and the experimental ones on the metal net made of copper-zinc alloy. The variable *m* represents the mesh size and *d* is the thread diameter.

It can be seen from Fig.4 that the two results fit well under different circumstance, and the relative errors are no more than 7.2%, which validate the simulation method is accurate enough.

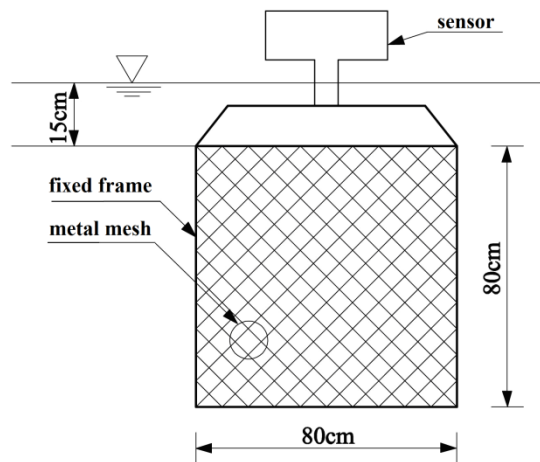


Figure 3. Experimental set up of net sheet

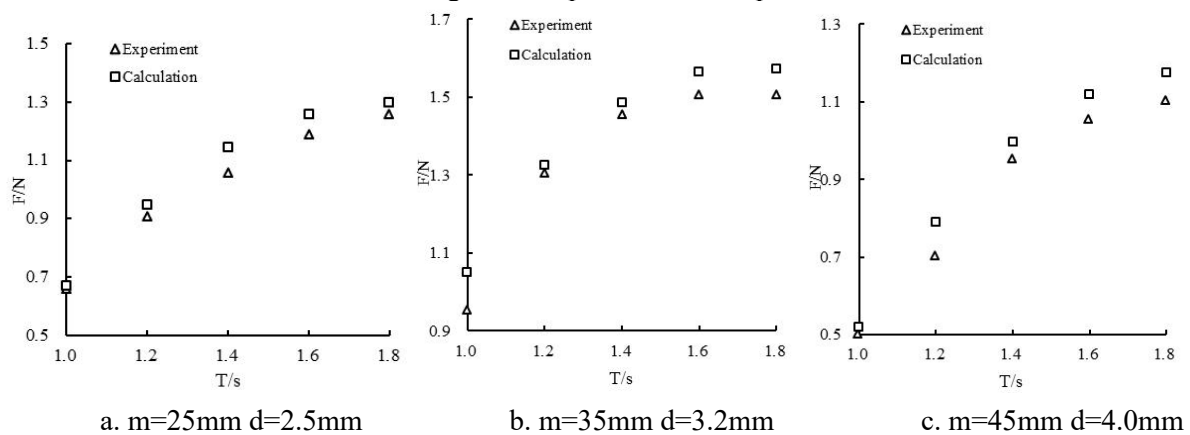


Figure 4. Comparison of calculation and test results of wave force

4. Results and discussions

In order to understand more detailed character of the wave force on metal net, the forces between different mesh size and thread diameter are analyzed.

4.1 Mesh Size

The comparisons of net forces between different mesh sizes are shown in Fig.5. It can be seen from the figures that the force decreased when the mesh size increased in all conditions.

4.2 Thread Diameter

The comparisons of wave forces between different thread diameters are shown in Fig.6. When the mesh sizes are same, the thicker the lines are, the larger the net forces are, since the total resisting area in the wave field is much larger.

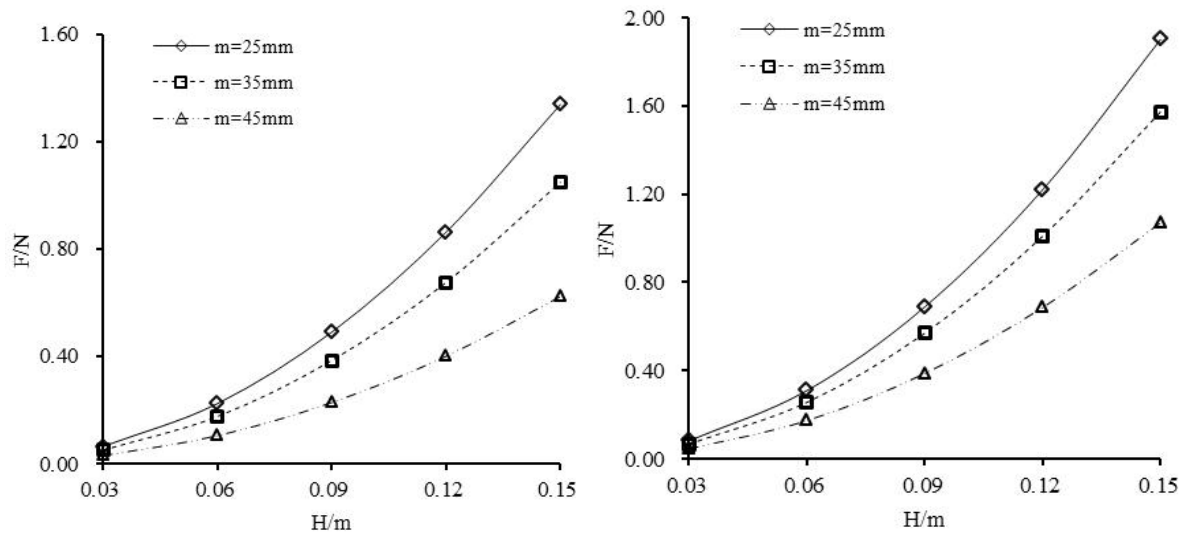
a. $d = 3.2$ mm $T = 1.0$ sb. $d = 3.2$ mm $T = 1.8$ s

Figure 5. Comparisons of net forces between different mesh sizes

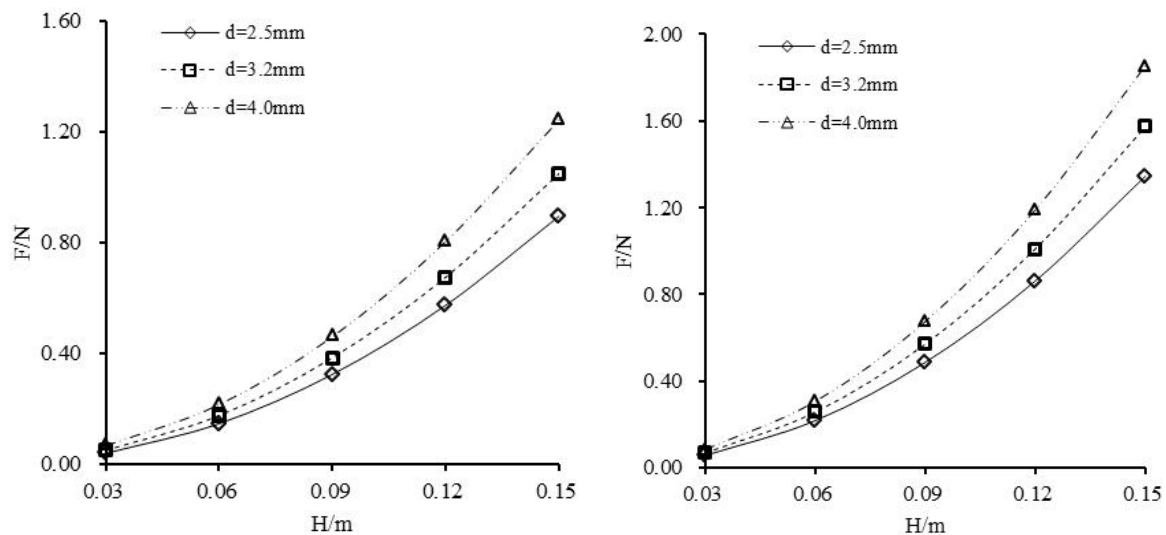
a. $m = 35$ mm $T = 1.0$ sb. $m = 35$ mm $T = 1.8$ s

Figure 6. Comparisons of wave forces between different thread diameters

5. Conclusions

Based on the FEM model and the Morison Equation, the wave force on the metal net under regular wave is calculated, and the conclusions are as follows.

(1) The simulated method is a good way to study the wave force on the netting, as the comparison between the simulated and experimental output verified the accurate of the mathematical model.

(2) The wave force on the netting changed with the mesh size and thread diameter. The force increased with larger diameter and smaller mesh size, since the effective area in the wave field increased.

Acknowledgments

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