Fault Characteristics of Breakage on Net Sheet of Aquaculture Net Cage

Zongyu Chang[1,2] ,Xianyi Zhou[1], Mingtao Chi[1], Zhongqiang Zheng[1]
1. College of Engineering
Ocean University of China
Qingdao, China
2. Key Laboratory Ocean Engineering Lab of Shangdong Province
Qingdao, China
zongyuchang@ouc.edu.cn

JianMing Yang[3]
3. Memorial University of Newfoundland
StJohn's, Canada

Abstract—**With the attention on the protection of onshore environment and quality of marine culture, offshore aquaculture attracts the research on its performance. The net cage is one of the most important facilities of offshore aquaculture. Breakage on net sheet has obvious effects on the safety of net cage. In this paper, the fault feature of breakage of net sheet is studied. Firstly breakage of net sheet is modeled. Then the dynamic model of net sheet with/without breakage is developed. The condition of net sheet with/without breakage is obtained. The difference on the tension distribution on net sheet and floating collar is analyzed between with breakage and without breakage. The difference of tension distribution can be considered as fault characteristic to identify the existence of fault of breakage.**

Keywords- net cage; breakage; fault characteristic; net sheet

I. INTRODUCTION

With the attention on the protection of onshore environment and quality of marine culture, offshore aquaculture is developed quickly. Net cages are the key facilities for offshore aquaculture. Under serious sea condition, offshore net cages suffer from sea load. It can bring the challenge about the safety and reliability of the cage structure and the cage operating platform.

Plenty of researches on cage structure have been carried out. Lader et al. [1] established a motion model of the net and used the model to study the effects of current velocity, wave height and net orientation relative to waves and current on the behavior of the net. Li et al. [2,3] dealt with solve the instantaneous buoyancy problem of floater in waves by applying Buoyancy Distribution method, studied the motions of floating collar and the deformation of net under different wave and current conditions and analyzed the hydrodynamic response of gravity cages based on appropriate irregular waves spectrum. Bi et al. [4, 5] conducted a series of experiments to study the damping effect of net cages in current and waves, analyzed the interaction between the flow and net cage based on porous-media fluid model. Lee et al. [6] established a mathematical model for fish cage system with netting, mooring lines and floating collar and analyzed the performance of large fish cage system under the current and waves by using the mass-spring model. Zhao et al. [7] studied the dynamic response of gravity cages under different wave-current conditions based on the lumped mass method and rigid-body dynamics. Li et al. [8] conducted a preliminary research on the ship-type floating fish farm, calculated the global response and the loads on mooring line under various waves and current conditions. Huang et al. [9] calculated tension force on the mooring line, the rate of volume reduction and pitch angle of the floating-collar and found that the mooring line force, the wave-current force and the volume reduction rate were proportional to wave height as well as current velocity; and the relationship between the wave period and response of net cage is not obvious. Wan [10] and Zhao [11] studied the tension distribution on the net under different sea load and the work is the base for the study of safety and integrity of net cage. Some fault of net cage such as breakage of net or mooring line can cause serious consequence. It is important to summarize the fault characteristics and estimate the safety of net cage.

In this paper, the fault characteristic of net cage with breakage is studied. The motion models of net cage with/without breakage are developed and numerical method is applied to obtain the condition of tension distribution of net cage. The effects of damage on the tension distribution of net cage are analyzed.

II. CAGE STRUCTURE

The gravity net cage includes floating collar, net sheet, weight patterns and anchoring system.

A. Floating collar

In order to reduce the difficulty of calculation, the mass of other parts can be converted to the main floating tube. Since the

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diameter of the floating tube is very small compared to the wavelength, the effect of the floating structure on the wave-current field is negligible. The lumped mass method is used to divide the floating frame structure into a plurality of micro-segments, each of which corresponds to a slender cylinder. Think of the floating collar as a rigid body, the interaction between the individual segments isn't considered. The external forces act on the particle of each micro-segment respectively.

The gravitational force of micro-segment:

$$G_i = G / N \tag{1}$$

where G is the total weight of the floating collar, N is the total number of micro-segments.

This study only considers the case where the floating collar is completely immersed in water. The buoyant force of micro-segment:

$$f_i = \rho_\omega g \cdot A_i \cdot l_i \tag{2}$$

where ρ_w is the density of water, g is the acceleration of gravity, A_i is the cross-sectional area of the floating collar, l_i is the length of each micro-segment.

$$\begin{aligned} F_x &= \frac{1}{2} C_\tau \rho_\omega A_x \left| u_x - U_x \right| \cdot \left(u_x - U_x \right) \\ F_Y &= \frac{1}{2} C_n \rho_\omega A_y \left| u_y - U_y \right| \cdot \left(u_y - U_y \right) \end{aligned} \tag{3}$$

where C_τ and C_n are the hydrodynamic coefficients in the x and y direction, A_x and A_y are the effective projected area in the x and y direction, u is the velocity of water particle, and U is the velocity of the component particle.

B. Net

The entire net is woven from a lot of net wires. In this paper, the whole net is divided into several nodes and components based on the lumped-mass method, and the ends of each components are set as mass points, and the quality of the mass points is half of the quality of all the component around it. Assume that the shape of the mass point is a sphere, and each mesh bar is treated as a separate component. With waves and current, the net is affected by various external forces (buoyancy, gravity and wave-current) and internal forces (wire tension). It is shown in Figure 1.

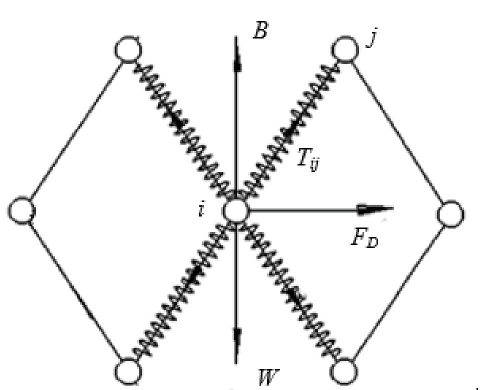


Figure 1. The force of mesh knot

The gravitational force of mesh knots:

$$W = \rho g \forall \tag{1}$$

where ρ is water density, g is gravitational acceleration, $\forall$ is the volume of water for the netting wire.

$$B = \rho_w g \forall \tag{2}$$

The tension between the node i and the adjacent node $j(j = 1, 2, 3, 4)$ can be expressed as:

$$T_{ij} = \begin{cases} AC_1 \left(\dfrac{l_{ij} - l_0}{l_0} \right)^{C_2} & l_{ij} > 0 \\ 0 & l_{ij} \le 0 \end{cases} \tag{3}$$

$$l_{ij} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2} \qquad (j = 1, 2, 3, 4) \tag{4}$$

where l_0 is the original length of among knots, l_{ij} is the length after deformation, A is the sectional area of the mesh knots, while C_1 and C_2 are the elastic coefficients of the flexible net material. For the elastic coefficients of polyethylene (PE) material, $C_1 = 3.454 \times 10^8$ and $C_2 = 1.0121$.

$$\begin{cases} F_{Dj\tau} = \dfrac{1}{2} \rho C_{D\tau} A_p U_R \left| U_R \right| \overline{e_\tau} \\ F_{Djn} = \dfrac{1}{2} \rho C_{Dn} A_p U_R \left| U_R \right| \overline{e_n} \end{cases} \tag{5}$$

where $C_{D\tau}$ is the drag force coefficient, A_p is the projected area of the mesh knots, U_R is the relative velocity of the fluid flow an d the mesh knots, C_{Dn} is the lift force coefficient.

Then the equation of motion of the node is:

$$m_i \ddot{s}_i = B + W + F_D + \sum_{j=1}^{4} T_{ij} \tag{6}$$

where m_i is the node mass, s_i is the displacement of node.

The weight patterns of the net cage are composed of sinkers without bottom ring. There are sinkers evenly distributed at the bottom of the net. Parameters related to net clothing are shown in table 1. The mooring system is replaced by four springs in the form of a four-point mooring.

TABLE I. PARAMETERS RELATED TO NET CLOTHING

Component	Value	Unit
Mesh	160	
Height	1.44	*m*
Diameter of the netting wire	1.8	*Mm*
Material	PE	
Mesh size	45	*Mm*
Density of water	1025	*Kg/m3*
Sinkers	32	
Sinker mass	200	*g*

The net cage is modeled using the multi-body dynamics program MSC Adams, and the cage is always below the water face during the simulation. The model is shown in Fig.2.

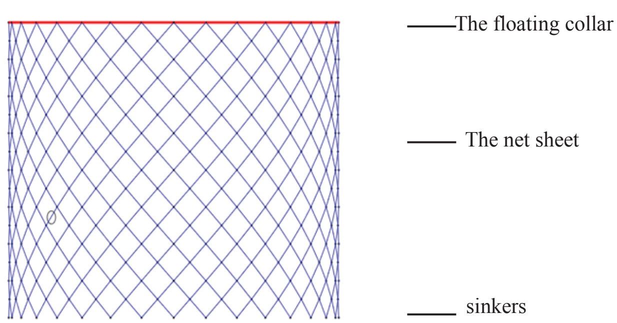


Figure 2. The model of net cage

To make tension distribution more intuitive: the net sheet is unfolded in the counterclockwise direction, and the plane expanding view of tension distribution is obtained. The specific mode is shown in Fig.3.

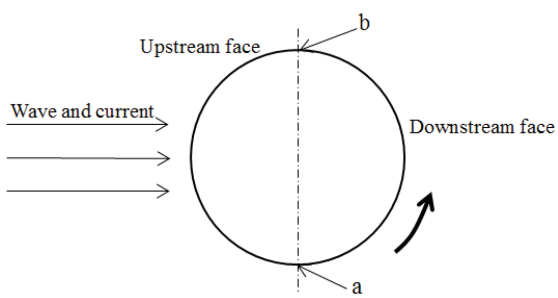


Figure 3. The unfolded method of circular net (top view)

Fig.4 is the expanding view of the mesh. The netting twine where the boundary a is located is numbered 1, and numbered sequentially. The damaged position of the net sheet selected in this paper can be better observed from Fig. 4. The damaged netting twine is numbered 51 and the break is on line 12.

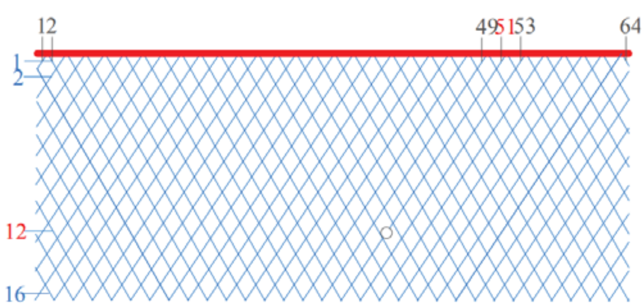


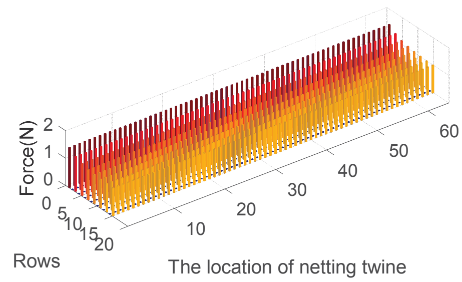
Figure 4. The location of breakage on the net

III. Results and Discussion

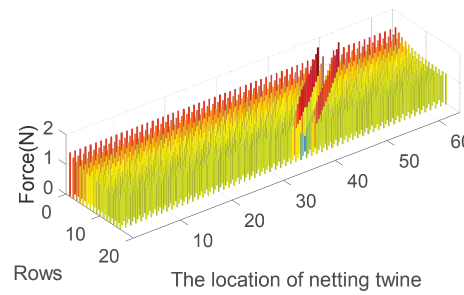
In this paper, the net cage is simulated at different sea states, including still water and wave current condition.

A. *Still water*

When the cage is in a still water environment, the nodes are only affected by buoyancy, gravity and cable tension. The tension distribution of the netting twine in still water environment is shown in Fig.5, and the force characteristic of floating collar is shown in Fig.6. As can be seen from Fig.5, since the spatial shape of the mesh is cylindrical, the same wire is uniformly distributed in still water. When the damage occurs, the original uniform distribution of the tension of the netting twine is broken.

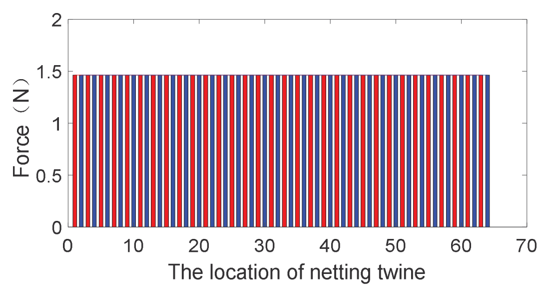


(a)Undamaged net sheet

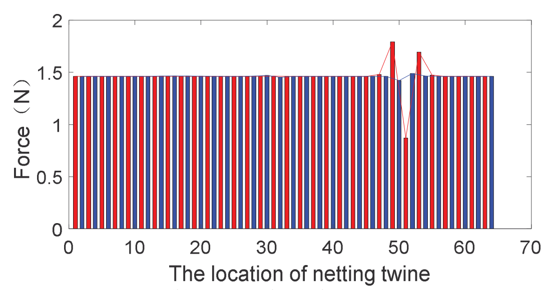


(b)Damaged net sheet

Figure 5. The tension distribution of the netting twines in still water



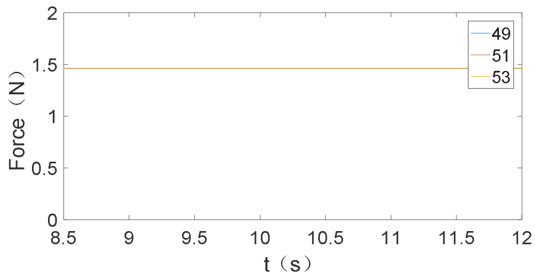
(a)Undamaged net sheet



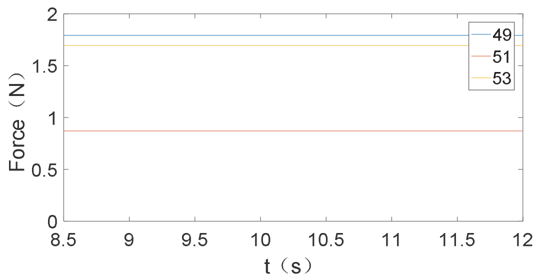
(b)Damaged net sheet

Figure 6. The force characteristic of floating collar in still water

As shown in Fig.6, the force of the damaged twine and the adjacent parallel line are changed. The damaged netting twine is numbered 51, and the parallel and adjacent netting twines are numbered 49 and 53. Fig.7 shows the change of the tension of the three netting twines on the floating collar in still water, and the growth rate of the tension of the three netting twines on the floating collar is shown in Fig. 8.



(a) Undamaged net sheet



(b)Damaged net sheet

Figure 7. The change of the tension of the three netting twines on the floating collar in still water

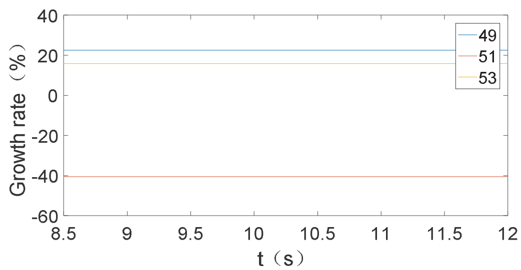
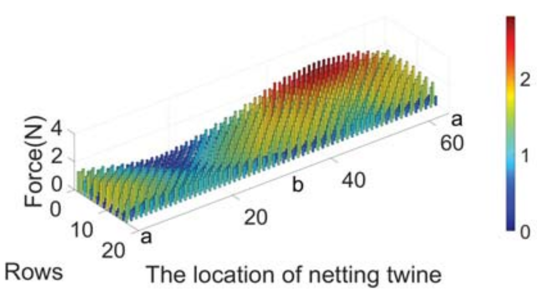


Figure 8. The growth rate of the tension of the three netting twines on the floating collar in still water

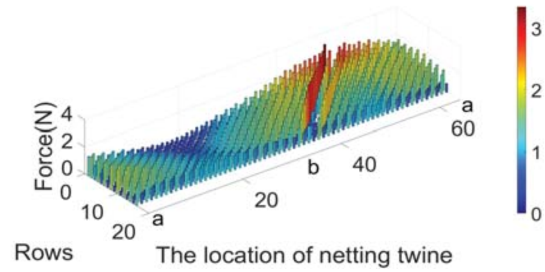
Comparing Fig.7 (a) and 7(b), it can be seen that the tension of the damaged netting twine on the floating collar is reduced, and the tension of the netting twines numbered 49 and 53 is increased to varying degrees. The tension of No.49 and No.53 netting twines is increased by nearly 20%, and the tension of the damaged netting twine is reduced by 40%. As shown in Fig.8.

B. Wave current condition

The results of this part are obtained in waves and current environment where the current velocity (U) = 0.33m/s, wave height (H) = 0.25m, and the wave period (T) = 1.2s.

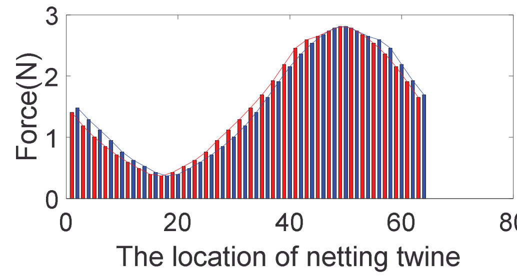


(a)Undamaged net sheet

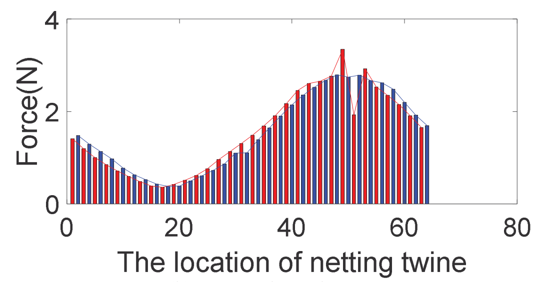


(b)Damaged net sheet

Figure 9. The tension distribution of the netting twines in wave and current



(a)Undamaged net sheet

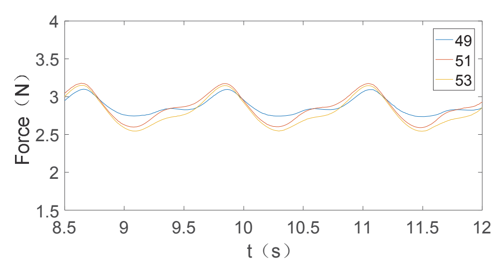


(b)Damaged net sheet

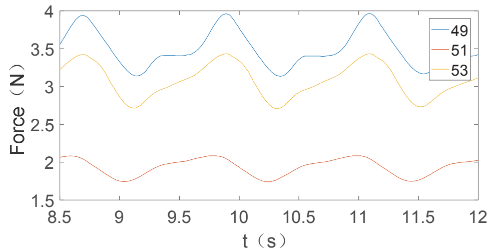
Figure 10. The force characteristic of floating collar in wave and current

Fig. 9 is a simulation diagram showing the tension distribution of the netting twine in wave and current when t=3/4T. However, when the damage occurs, the specific change of the tension distribution is shown in Fig. 9(b).

Fig.10 shows the change of the tension of the three netting twines on the floating collar in wave and current when t=3/4T. From the comparison of the left and right figures, the tension of the damaged netting twine is reduced, and the tension of the netting twines numbered 49 and 53 is increased, and the tension of other network cables hardly changes.



(a) Undamaged net sheet



(b)Damaged net sheet

Figure 11. The change of the tension of the three netting twines on the floating collar in still water

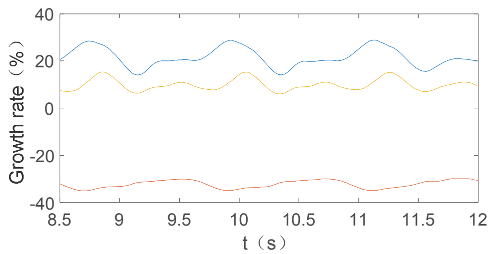


Figure 12. The growth rate of the tension of the three netting twines on the floating collar in still water

Fig.11 shows the change of the tension of the three netting twines on the floating collar in wave and current. The tension of No.49 and No.53 netting twines is increased by nearly 20%, and the tension of the damaged netting twine is reduced by 30%. As shown in Fig.12.

C. *Fault characteristics of net cage with breakage*

From the results it is found that the effects of damage of net sheet on tension distributions of net sheet and floating collar are obvious and the tension distribution can reflect the existence and location of damage on net sheet. Considering the feasibility of measurement, the tension distribution of floating collar can be easily obtained. So it can be a useful means to predict and estimate the safety of net cage.

IV. Conclusion

The fault characteristics of net cage are studied. Based on the lumped method, the model of net cage is set up. The dynamic characteristics of net with breakage are obtained under different wave-current conditions. The influence of damage on tension distribution is analyzed. The results show that the tension of the damaged wire reduces, and the tension of the two adjacent wires that are parallel to the broken wire will increase, while the tension of other wires has barely noticeable difference. It is difficult to find in the water after net is damaged, which is easy to cause a large number of fish to escape. The work can provide the theoretical reference for the improvement of safety of net cage.

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References

[1] P. F. Lader, and A. Fredheim, "Modelling of Net Structures Exposed to 3D Waves and Current."

[2] L. Li, S. X. Fu, Y. W. Xu, J. G. Wang, and J. M. Yang, “Dynamic responses of floating fish cage in waves and current,” Ocean Engineering, vol. 72, pp. 297-303, 2013.

[3] L. Li, S. X. Fu, and Y. W. Xu, “Nonlinear hydroelastic analysis of an aquaculture fish cage in irregular waves,” Marine Structures, vol. 34, pp. 56-73, 2013.

[4] C. W. Bi, Y. P. Zhao, G. H. Dong, Y. N. Zheng, and F. K. Gui, “A numerical analysis on the hydrodynamic characteristics of net cages using coupled fluid–structure interaction model,” Aquacultural Engineering, vol. 59, pp. 1-12, 2014.

[5] C. W. Bi, Y. P. Zhao, G. H. Dong, Y. Cui, and F. K. Gui, “Experimental and numerical investigation on the damping effect of net cages in waves,” Journal of Fluids and Structures, vol. 55, pp. 122-138, 2015.

[6] C. W. Lee, J. Lee, and S. Park, “Dynamic behavior and deformation analysis of the fish cage system using mass-spring model,” China Ocean Engineering, vol. 29, no. 3, pp. 311-324, 2015.

[7] Y. P. Zhao, Y. C. Li, G. H. Dong, F. K. Gui, and B. Teng, “A numerical study on dynamic properties of the gravity cage in combined wave-current flow,” Ocean Engineering, vol. 34, no. 17, pp. 2350-2363, 2007.

[8] L. Li, Z. Y. Jiang, and M. C. Ong, "A Preliminary Study of a Vessel-Shaped Offshore Fish Farm Concept."

[9] X. H. Huang, G. H. Guo, Y. Hu, Q. Y. Tao, and X. M. Zhang, “Numerical simulation of forces and motion deformation of deep-water net cages in waves and currents,” Journal of Fishery Sciences of China, vol. 18, no. 2, pp. 443-450, 2011.(in Chinese)

[10] R. Wan, Fuxiang Hu, Tadashi Tokai. A static analysis of the tension and configuration of submerged plane nets. Fisheries Science 2002; 68: 815–823

[11] Y. P. Zhang, Y. C. Li, G. H. Dong, W. S. Liu, and F. K. Gui, “Tension distribution of gravity cage net in steady current,” Fishery Modernization, vol. 35, no. 6, pp. 5-8, 2008. (in Chinese)