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ANALYSIS OF PLANE NETTING WITH TWINE BREAKAGE IN AQUACULTURE NET CAGE

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Key words: netting, twine breakage, dynamic model, tension distribution.

ABSTRACT

Offshore fish cage is one of the most important facilities for marine aquaculture farm. Existence and development of netting breakage can cause severe consequences, e.g., escape of fish, structure failure of cages, economic losses and ecological hazards. This paper presents the dynamic analysis of netting with breakage in fish cage under the influence of currents. The dynamic model of plane net with/without twine breakage is developed by using lumped mass method. The numerical integration method is employed to solve the differential equations. The effect of twine breakage on the shape of net and the tension distribution on the netting and supporting bar are investigated as well. The simulation results showed that the tension distribution on supporting bar can be utilized to predict netting breakage.

I. INTRODUCTION

Offshore fish cage is widely used in marine aquaculture farms to improve the quality of fish and increase the culture benefit The fish cage systems suffer from harsh external environment, e.g., wind, wave, and current, which makes it a great challenge to avoid damage. The failure of fish cage system mainly comes from operational mistakes, breakage of mooring lines, and the collision between chains and net (Faltinsen, 2014). According to statistical analysis, the main reason for the escape of fish is due to the damage of net and two-thirds of the escape incidents result from holes in the net, leading to great economic losses and potential ecological threat. (Jensen et al., 2010). Therefore, it is crucial to analyze the dynamic behaviors of netting with damage.

Extensive research focuses on the dynamic analysis of fish cages to get the performance under currents and waves. Using lumped-mass method, Huang et al. (2006, 2007) and Lee et al. (2008) studied a series of gravity cages, and the dynamic response of floating collar and volume reduction coefficient are analyzed in detail. Lee et al. (2008) studied the performance of a fish cage system with a floating collar using the mass-spring model. Zhan et al. (2006) and Zhao et al. (2007) studied the effects of structure size, mesh type and cage shape on the net cage deformation and drag force. Li et al. (2013) and Moe et al. (2009) applied the finite element method (FEM) technique to study the dynamic response of a gravity cage with a floating system. Huang et al. (2010) and Decew et al. (2010) analyzed the dynamic behavior of a single-point mooring net cage system under currents. Compared with the multi-point and spread mooring fish cage, the single point mooring fish cage can comply with the current direction and reduce the drag force on the net significantly. To improve the performance of a fish cage, new materials are adopted and the behaviors are analyzed. Lee et al. (2015) and Gansel et al. (2012) studied the hydrodynamics of fish cage net, which are composed with copper and synthetic, respectively. The corresponding properties of copper net and synthetic net are compared as well.

As a basic component of fish net cage system, netting is crucial and the study of netting is able to provide ample details about the properties of local domain in the net. Netting is the basic component of fish net cage system and the intensive study on netting can help us to understand the details of properties or condition of local domain in the net. Wan et al. (2002) discussed the equilibrium configuration and tension distribution of a net in a uniform current by non-linear finite element method. Lader and Fredheim (2006) studied the dynamic properties of a flexible netting using a numerical model in waves and currents. Li et al. (2006) investigated configuration and tension distribution for different mesh types of netting. Huang et al. (2009) employed the lumped mass method to analyze the effects of current and ballast on the force and deformation. Although plenty of research on net cage and netting has been carried out, the dynamic characteristic of netting with breakage still didn't analyzed.

In this paper, the dynamic responses of the plane nets considering twine breakage under currents are studied. The dynamic modelling of plane net is derived using lumped mass method in Section II. The simulation results and analysis of netting with twine breakage are shown in Section III, and concluding remarks are given in Section IV.

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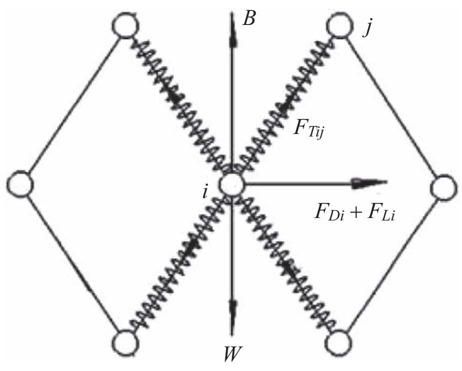
(a) A part of fishing netting



(b) The forces of knot

Fig. 1. Schematic diagram of the model used for the calculation for mesh knots.

II. DYNAMIC MODELLING OF NETTING

In this study, we consider a fishing netting with a supporting bar above and a ballasting bar below as shown in Fig. 1(a). The lumped mass method is utilized to model the plane net as node mass connecting with massless spring. The lumped point masses are set at each knot and the mass of nodes is equal the mass of knot plus the four of the mass of the half of mesh bar. The hydrodynamic force is assumed to be acted on the mass point. Then, we can analyze the force on the mass point. The forces of knot are shown in Fig. 1(b), including weight W, buoyancy B, drag force F_D, lift force F_L, and tension force F_T.

The equation of motion for each mesh knot can be described as follows:

$$\left(m + \Delta m\right)\ddot{\vec{q}} = \vec{W} + \vec{B} + \vec{F_D} + \vec{F}_L + \vec{F_T} \tag{1}$$

where, m is the mass of the mesh knot, Δm is the added mass and $\ddot{\vec{q}}$ is the acceleration vector.

The added mass of the mesh knot is represented as,

$$\Delta m = \rho \forall C_m \tag{2}$$

where, ρ is the density of sea water, $\rho = 1025$ kg/m^3, $\forall$ is the volume of mesh knots and C_m is the added mass coefficient, C_m is assumed to be 1.5 according to Lee et al. (2008).

The gravity of mesh knots is expressed as,

$$W_i = m_i g \tag{3}$$

where, g is the gravity acceleration.

The buoyancy term of mesh knots is,

$$B_i = \rho g \forall_i \tag{4}$$

where, ρ is the density of sea water, $\forall_i$ is the volume of the *ith* mesh knots.

The *ith* node point is suffering from the tension force from the adjacent mass points along the direction of twines in the mesh as well. The magnitude of tension force between two adjacent nodes is determined by the material properties, cross section area and relative displacements. The tension force of node i from node j can be written as

$$F_{Tij} = \begin{cases} AC_1\left(\dfrac{l_{ij} - l_0}{l_0}\right)^{C_2} & l_{ij} > l_0 \\ 0 & l_{ij} \le l_0 \end{cases} \tag{5}$$

$$l_{ij} = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - j_i\right)^2 + \left(z_j - z_i\right)^2} \quad (j = 1, 2, 3, 4) \tag{6}$$

where, l_0 is the original length, l_{ij} is the deformed length, A is the sectional area of the mesh knots, C_1 and C_2 are the elasticity of the element. C_1 and C_2 can be obtained from Fibre Ropes for Fishing Gear by Klust (1983). For PE material, $C_1 = 3.454 \times 10^{-4}$ and $C_2 = 1.0121$. However, the tension force of the damage of the plane net would change. If the damage occurs between the mesh knots, the tension force would become zero.

The hydrodynamic forces of mesh knots can be calculated by Morison Equation. The current is assumed to be steady and uniform, so the inertial force is neglected. For the moving mesh knots, the drag forces and lift forces can be generalized as Huang et al. (2009).

$$\overline{F_{Di}} = -\frac{1}{2}\rho C_D A_p U_R \left|U_R\right| \overline{n_D} \tag{7}$$

$$\overline{F_{Li}} = \frac{1}{2}\rho C_L A_p U_R \left|U_R\right| \overline{n_L} \tag{8}$$

where, C_D is the drag force coefficient, A_P is the projected area of the mesh knots, U_R is the relative velocity of the fluid and the mesh knots, $U_R = U - R$, U is the resultant velocity vector, R is the motion velocity vector of the mesh knots, and $\overline{n_D}$ is the unit vector for drag and acts in the opposite direction of the relative velocity vector. C_L is the lift force coefficient, and $\overline{n_L}$ is the direction of the lift force.

Table 1. Calculation condition for net model.

Item	Condition
Material	Polyethylene (PE)
The density of PE (kg/m^3)	953
Mesh size (mm)	75
Diameter of twine (mm)	3
Number of elements (mm)	852
Density of water (kg/m^3)	1025
Weight of bar (N)	16.38
Drag force coefficient C_D	1.3
Lift force coefficient C_L	0.1
Added mass coefficient C_M	1.5

The direction of lift forces for each mesh knot was obtained from the vector product $\overline{U}\times\left(\overline{U}\times\overline{R}\right)$ and the particular direction of the unit vector $\overline{n_L}$ can be expressed as

$$\overline{n_L}=\frac{\overline{U}\times\left(\overline{U}\times\overline{R}\right)}{\left|\overline{U}\times\left(\overline{U}\times\overline{R}\right)\right|} \quad (9)$$

As forces on component nodes of fish cage have been analyzed, the governing equation of the model can be obtained by integrating all the nodes. The non-linear second-order differential equation in matrix form can be shown as:

$$M\overline{\ddot{q}(t)}=\overline{W(t)}+\overline{B(t)}+\overline{F_D(t)}+\overline{F_L(t)}+\overline{F_T(t)} \quad (10)$$

where, M is the mass of the mesh knot, $\overline{\ddot{q}(t)}$ is the acceleration.

Numerical integration method such as the fourth-order Runge-Kutta algorithm can be used to solve the Eq. (10).

III. SIMULATION RESULTS AND DISCUSSION FOR THE FISH CAGES

In this section, the dynamic performance of the netting considering twine breakage in current is analyzed in detail. The structure of netting is shown in Fig. 2. The top of plane net is fixed on a supporting metal bar, and the bottom of plane net is ballasted with another bar of length 1.89 m. The detailed parameters for calculation are listed in Table 1.

1. Profile of Netting

The steady configure/shape of net with/without twine breakage under different currents are obtained based on the motion equations in Section II. When the current is equal to 0.33 m/s, the equilibrium configurations without/with breakage are shown in Fig. 3. The circle in Fig. 3(b) represents a twine breakage point and the position is set to be at the intersection between 21st column and 8th row. From Fig. 3, we find that the profiles of netting with or without twine breakage in a mesh are similar and it is difficult to identify the existence of a small hole or breakage in a mesh of netting. In addition, much more deformation occurs in the middle of left and right edges of plane net than other locations of plane net and this part of net appears slack. When the current is set to be 0.11 m/s, 0.22 m/s, 0.33 m/s, and

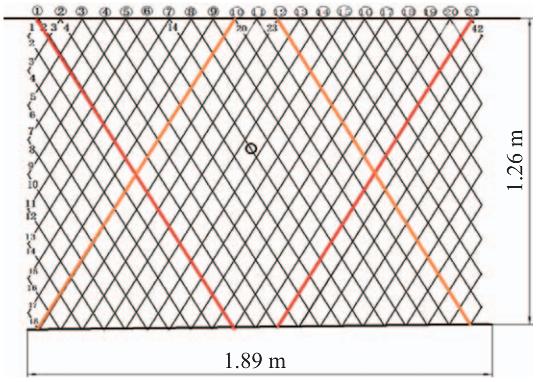
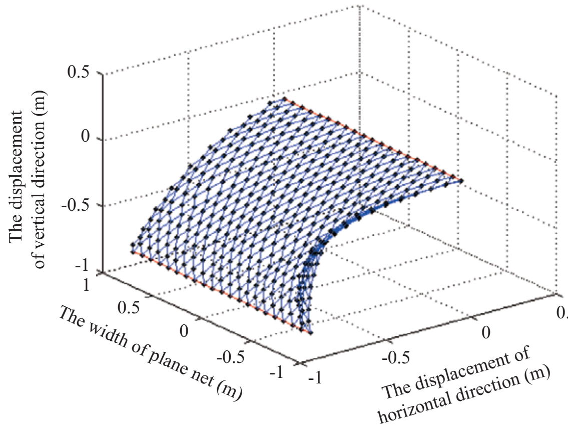
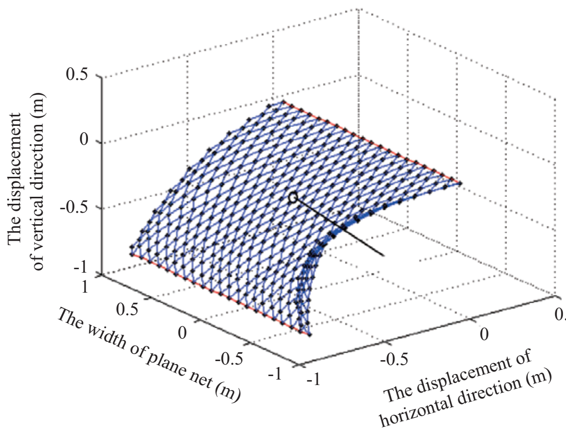


Fig. 2. Structure of plane net.



(a) Without breakage



(b) With twine breakage in a mesh

Fig. 3. The steady shape of plane net in current.

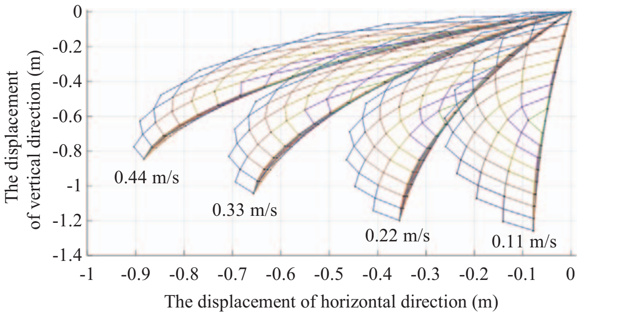


Fig. 4. Side view of profile of netting in different current with breakage.

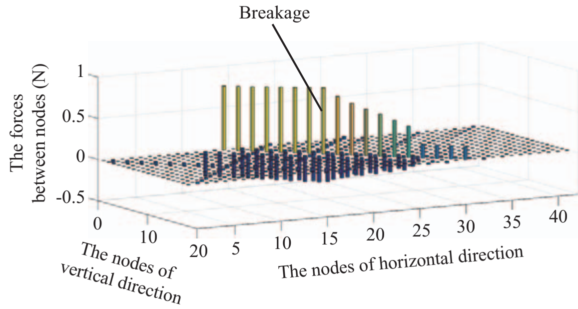
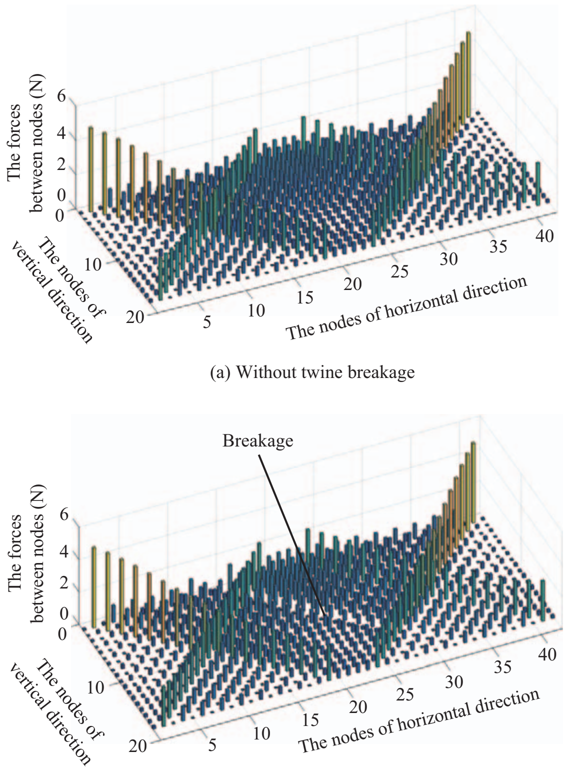


Fig. 6. Difference between condition of netting with twine breakage and twine breakage.



(a) Without twine breakage

(b) With twine breakage

Fig. 5. Tension Distribution on netting.

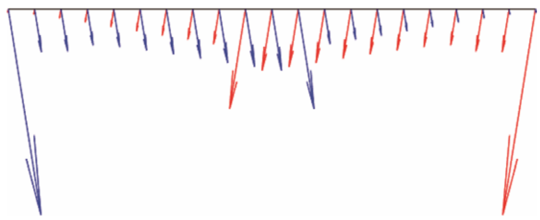


Fig. 7. The scheme of forces on up supporting bar.

0.44 m/s, respectively, the steady configurations of plane net are shown in Fig. 4.

2. Tension Distribution on Netting

The tension distributions of netting without breakage is calculated under a irrotational and constant current (0.44 m/s) as shown in Fig. 5(a). From Fig. 5(a), we know that the relative higher forces are along the diagonal line of plane net, and the relative smaller forces lie on both sides of the plane net.

The tension distribution is shown in Fig. 5(b) when considering twine breakage. There is a marked change in tension force around the breakage zone. The tension forces decrease diagonally crossing the breakage point. However, the tension forces increase on the two diagonal lines near the breakage point. For the sake of observation, the difference of tension distribution on the netting without/with breakage is shown in Fig. 6.

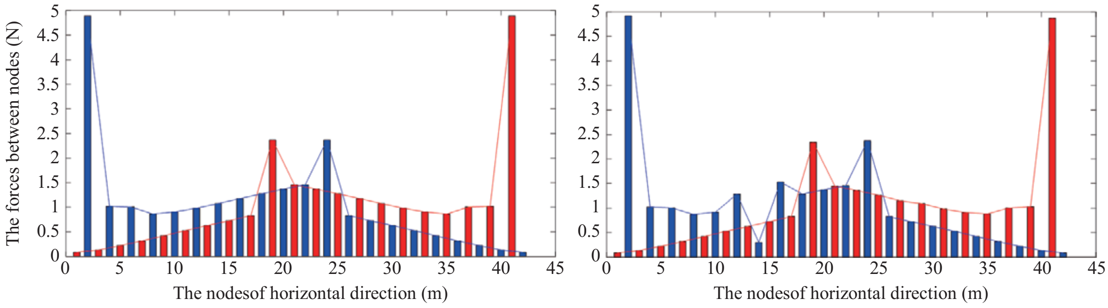
3. Tension Force Distribution of Twine on Supporting Bar

In the previous description, it can be seen that the distribution of tension force on netting can reflect the condition of breakage of twine. However, in practice, it is difficult to obtain the distribution of tension on netting and it can't be used as an index to identify the breakage of net. To overcome the disadvantage of tension force distribution, the force on supporting bar with netting is discussed in this section. So the force on supporting bar crossing the twines are shown in Fig. 7. The forces are distributed symmetrically. To compare the effect of breakage point on force, The forces between nodes are represented using bar graph, as illustrated in Fig. 8. From Fig. 8(a), the value of force between nodes is symmetrically when there are no breakage point on twines. However, if the twine has breakage, The symmetry will be changed, as shown in Fig. 8(b). The changing force is in the diagonal direction of the breakage point.

From the figures above, the sensor can be measured the force on twine through the changed, the approximate position of the breakage point can be estimated.

IV. CONCLUSION

This paper studied the dynamic response of plane net with breakage under currents. The mathematical model of netting with twine breakage is developed using lumped mass method. The steady shape of netting, tension force distribution on the netting and supporting bar are calculated. This work is very useful for studying the trends of netting breakage. Some conclusion are deduced as following:



(a) Without breakage (b) With twine breakage

Fig. 8. Blue bar is the force lower right; red bar is force to lower left.

1. The effect of single breakage point on the shape of the netting or cage is not obvious. The shape of plane net is hard to distinguish whether the net is breakage.
2. The existence of breakage point leads to the variety of the tension distribution of netting. Especially on the local area of breakage point, the variety of tension is more obvious.
3. The tension forces distribution are analyzed. From the results we found the forces are symmetry. If the breakage point exists on twine in plane net, the symmetry will be changed. The tension forces decrease crossing the breakage point and the tension forces increase on adjacent of the breakage point.
4. The tension distribution both on netting and supporting bar can reflect the breakage of twine. The tension force on supporting bar can be measured to determine the position of breakage of netting.

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