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Numerical simulation of the knotted nylon netting panel

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Abstract. A piece of netting, consists of the 8 8 meshes, fixed on a square frame, was simulated and the tensions and their distribution, the positions of knots and netting shape were calculated by means of MATLAB in computer. The dynamic mathematic model was developed based on lumped mass method, the netting was treated as spring-mass system, the Runge-Kutta fifth-order and sixth-order method was used to solve the differential equations for every step, then the displacement and tension of each mass point were obtained. For verify this model, the tests have been carried out in a flume tank. The results of the numerical simulation fully agreed with the experiments.

1 Introduction

In fishing gear design and operation performance improvement, the drag, tension distribution and shape has directly affected capture efficiency and energy consumption. Netting panels are the basic composition of fishing gear system and aquaculture facilities such as trawl and purse seine, so the hydrodynamic performance of netting panel is the important content of the fishing gear performance study.

In the past decades, when the scientist studied the dynamic behaviour of netting gear operation process, they tried to use numerical method and model for predicting. So, AARSNES et al. considered the net cage consist of many discrete netting panels, and used the hydrodynamic coefficients from model test to calculate the shape and internal force[1].Theret built a three-dimensional numerical model to simulate netting gear, and successfully developed a software which can compute the shape and tension distribution of trawl in constant speed[2].Bessonneau and Marichal used rigid bar element to build the dynamical model for the netting panel of trawl. They combined gravity force, buoyancy force, hydrodynamic force and point force, applied finite difference method to disperse time and iterative method to model the shape and drag of the equilibrious netting panel in several trawl boundary conditions[3]. Based on the mapping coefficient method, Gignoux et al. used bar element and applied commercial software ABAQUS/AQUA to develop netting panel model[4], the results were in accordance with the results of Mannuzaa[5]. Priour et al. used two-dimensional triangular element based on the finite element method to model net shapes in order to build the trawl model. But the drawback of these methods was that the bars must be parallel to the net twines and the sides of the membrane element parallel to the diagonal of the net meshes, so the user was not free for the discretization of the net. The element can not describe the deformation outside of the membrane element. The twines only located and deformed along the side of the element, this great restricted the maximum size of the element and needed some additional elements to sufficiently describe the whole net construction[6-7].

Takagi et al. used the lumped mass method to develop the NALA software to predict the three-dimensional shape of netting[8-9]. Yuan used statics model to analyze the drag and deformation of plane netting, cylindrical netting, cone netting and frustum netting based on their boundary conditions. The primary study was compatible with the flume tank measurements. The three dimensional numerical netting model was established to calculate and estimate the shapes, inter-tensions and their distribution[10]. Lee and Zhao established the numerical model to describe the hydrodynamic behavior and deformation of net cage and fishing netting for optimization design[11-12]. Li et al. developed a numerical model based on lumped mass method to set up the motion equations for rectangle and diamond meshes. The Runge Kutta Verner fifth-order and sixth-order method was used to solve these equations. The results agreed well with the experimental data from the flume tank test. The deformation of the diamond mesh netting was larger than the rectangle mesh one. In square mesh netting, the highest tension distributed along the four diagonal lines. In diamond mesh netting, the tensions

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distribution along four sides were the highest,but inside the net were the lowest[13].

Depending on the lumped mass-spring method, Sun et al. established a mathematical model for simulating the dynamic behaviour of a fishing net. The model was solved by Newmark- β method which can take large time steps stably. Using Open GL library software, they developed a three-dimensional visualization model [14].

Song et al. and Cao et al. established the dynamic model of the tuna longline, and modelled the space shape distribution and tension distribution in different conditions [15-16]. Hosseini et al. refined the mass-spring method to consider the drag coefficient as a function the Reynolds number and the attack angle in order to build the numerical model for the purse seine gear and attain the sinking performance of different designs and netting materials[17]. Zhang et al. thought the inertial mass coefficient on knotless netting model used in tuna purse seine is the key factor for sinking performance [18].

These study mainly considered that the external condition affected the netting gear shape and the hydrodynamic performance, but the self-characteristics of netting gear affecting the netting gear shape and the hydrodynamic performance was less considered. There are many types of netting panels, such as knotted, knotless, diamond, square and hexagon. In actual operation, the diamond meshes are applied widely, and the hydrodynamic performance of netting panel is the important component of the netting gear study. So, we built the mathematical-mechanical model to simulate the space shape and tension distribution of the diamond meshes.

2 Materials and methods

2.1 Numerical Modelling of the knot nylon netting panel

In our study, the nylon knotted netting panel was shown in figure 1. A virtual mathematical mesh model with 8 by 8 meshes was simulated based on the lumped mass-spring method(figure 2). It was assumed that a net was composed of many lumped mass points interconnected by springs without mass. The lumped mass points were set at each knot. To simplify the model, each mesh knot was considered as a spherical shape where the fluid dynamical coefficients in all directions were constant. There was no external force existing on the spring, and buoyancy, gravity and hydrodynamic force (lift force and drag force) acting on the mass points. The layout of mass points were shown in figure 3.

2.2 Mathematics-mechanical Equations

It was assumed that the netting panel was in a state with spatial-temporally uniform current flow. The motion of point i can be expressed by the following equation based on the Newton second law:

$$M_i a = \vec{T} + \vec{F} + \vec{W} + \vec{B} \qquad (1)$$

Where *a* is the acceleration vector of point i; *T* is the tension force acting on point i; *F* is the hydrodynamic force including drag force and lift force; *W* is the gravity force; *B* is the buoyancy force, and *M* is the mass of point i including the added mass of i.

The mesh bar is looked as a spring, based on the Hooke's law, the tension T could be expressed as:

$$|T_{ij}| = \begin{cases} k\left(l_{ij} - l_{0ij}\right) & l_{ij} > l_{0ij} \\ 0 & l_{ij} \le l_{0ij} \end{cases} \qquad (2)$$

Where, k is the stiffness of the mesh bar. l_{0ij} and l_{ij} are the original length and deformed length between mass points i and j, respectively.

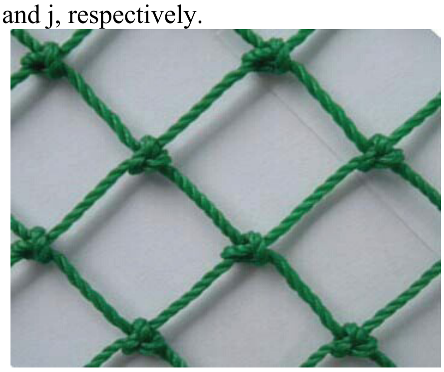

Figure 1. The knot plane net

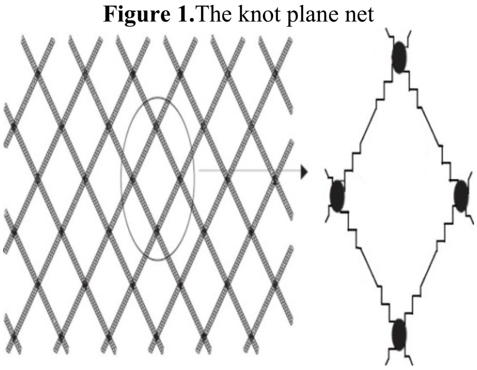

Figure 2. The spring-mass model

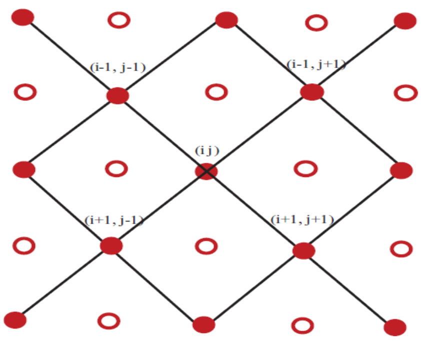

Figure 3. The layout of the quality point of plane net

As the mesh knot was considered as a spherical shape, so the hydrodynamic force can be expressed as the following equation

$$\mathbf{F}_s = \frac{1}{2} C_D \rho S_s \mathbf{V}^2 \qquad (3)$$

Where, $\mathbf{F}_s$ is the hydrodynamic force, C_D is the hydrodynamic coefficient, ρ is the water density, S_s is the projected area of mesh knot, **V** is the resultant speed vector.

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Because the fluid dynamical coefficients of mesh bars in all directions are different. Then the drag force ($\mathbf{F}_d$), lift force ($\mathbf{F}_l$) can be expressed as:

$$\mathbf{F_d} = \frac{1}{2} C_d \rho S_b \mathbf{V}^2 \qquad (4)$$

$$\mathbf{F}_l = \frac{1}{2} C_l \rho S_b \mathbf{V}^2 \qquad (5)$$

Where, C_d and C_l are the lift force coefficient and drag force coefficient, S_b is the projected area of mesh bar.

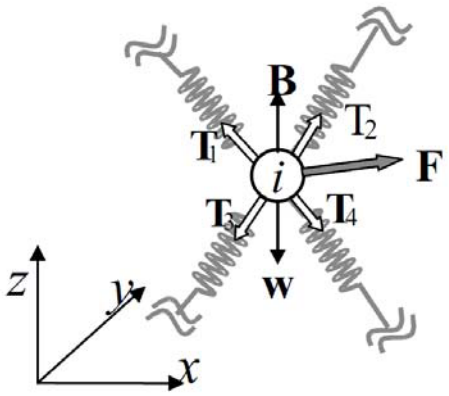

Figure 4. Schematic diagram of the model used for the calculations for mesh knots

So, the motion of the i-th lump mass point can be expressed as:

$$\begin{cases} M_i \ddot{x}_i = (T_x + F_{sx} + F_{dx} + F_{lx}) \\ M_i \ddot{y}_i = (T_y + F_{sy} + F_{dy} + F_{ly}) \\ M_i \ddot{z}_i = (T_z + F_{sz} + F_{dz} + F_{lz} + B_i - W_i) \end{cases} \qquad (6)$$

So, the equation (6) can be changed into ordinary differential equations:

$$\begin{aligned} \ddot{x}_i &= f_2(x_i, y_i, z_i, \dot{x}_i, \dot{y}_i, \dot{z}_i, x_1, y_1, z_1, x_2, y_2, z_2; t) \\ \ddot{y}_i &= g_2(x_i, y_i, z_i, \dot{x}_i, \dot{y}_i, \dot{z}_i, x_1, y_1, z_1, x_2, y_2, z_2; t) \qquad (7) \\ \ddot{z}_i &= h_2(x_i, y_i, z_i, \dot{x}_i, \dot{y}_i, \dot{z}_i, x_1, y_1, z_1, x_2, y_2, z_2; t) \end{aligned}$$

2.3 algorithm and simulation

The Runge-Kutta fifth-order and sixth-order method was used to solve the differential equations (7). The above algorithm was used to compile the program and to calculate the models in Matlab. These equations are solved numerically at all given points using a workstation HP 820. After that, the dynamics of the nylon knotted netting panel can be simulated.

3 The Results

After modeling and programming the nylon knotted netting panel using mechanical equations and implicit algorithm under Matlab, the motion process of the netting panel can be displayed (figure 5 and 6). The equilibrium state of netting panel agreed well to the observed data in flume tank test (figure 7). The tension distributions of the whole netting panel were shown in figure 8.

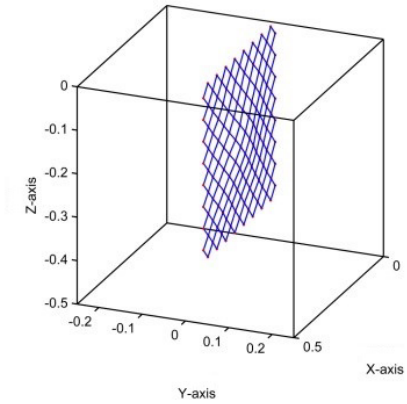

Figure 5. The initial position of the netting

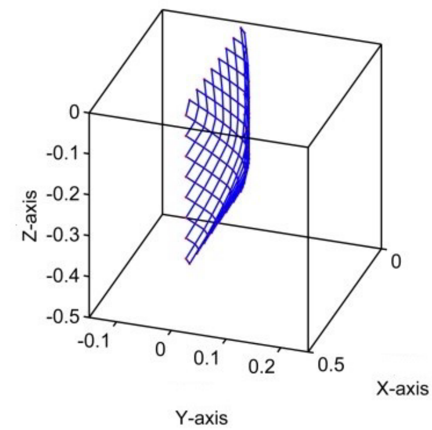

Figure 6. The equilibrium state of the netting

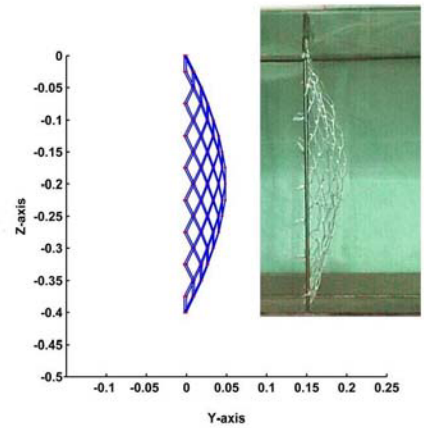

Figure 7. Comparison diagram

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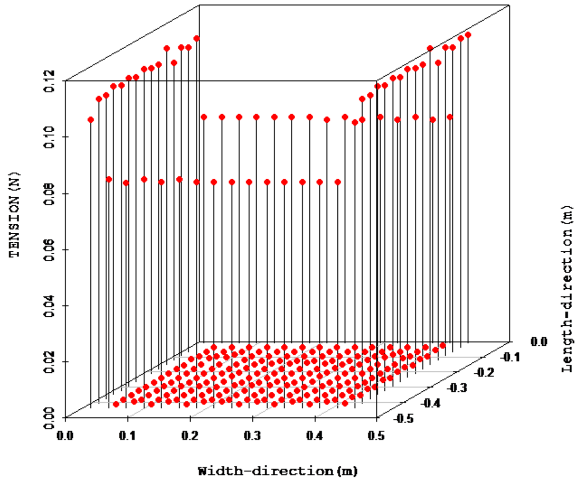

Figure 8. The Tension distribution of bars

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