ANALYSIS OF THE POSITIVE FORCES EXHIBITING ON THE MOORING LINE OF COMPOSITE-TYPE SEA CAGE

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ARTICLE INFO

***Article history*:**
Received: 1.6.2015.
Received in revised form: 1.9.2015.
Accepted: 23.9.2015.
Keywords:
Composite-type sea cage
Mooring line
Positive forces
Sea cage arrangements

Abstract:

According to the commonly used arrangements of gravity sea cages in deep sea farming, 5 composite-type working models are designed with model-based testing by which the forces acting on the mooring line are measured under pure current, pure wave and the combination of both. Meanwhile, the forces acting on the normal mooring line are also analyzed. Based on the test data, a conclusion is made about the characteristics of the mooring line force. In the end, some feasible suggestions are given, which should be adopted for arrangement of sea cages in real farming.

1 Introduction

The cage culture of marine fish is developing rapidly in China, and is heading for the direction of large-scale, intensification, industrialization and offshore deep-water. Composite-type sea cage has received more and more attention in the marine aquaculture in recent years [1]. Aquaculture farmers in coastal areas have widely adopted either composite-type sea cages from abroad or its Chinese domestic imitation product. Compared with the traditional small marine cage aquaculture system, it has such advantages as strong ability to resist wind and waves, large aquaculture capacity, high rate of growth, higher percent survival, long service life and little pollution. This paper mainly carries out experimental study into the forces acting on the mooring line of composite-type sea cages. We have designed a single model and 5 composite-type working models based on the prototype cage with 2-ring HDPE pipes in circular shape. The advantages and disadvantages of sea cages arrangements could be obtained through horizontal comparative research into force characteristics of the mooring line.

2 Experimental investigation

2.1 The design of composite-type sea cage models

According to the prototype sea cage data and the model scale λ (λ is the corresponding geometry dimension ratio of the prototype sea cage to the test model), we have finally completed the sea cage model design by simulating the floating collar system, netting model making, and with the simulation of sinker and anchor systems. Composite-type sea cage is evenly composed of several single sea cages in a certain arrangement. The test sea cage models have five types including composition model A, B, C, D and E. They are shown in Fig.1. The Arabic numerals in Fig.1 are the mooring line numbers.

2.2 Testing equipment

The experiments were carried out in the wave tank at the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology [2]. It is 56m long, 34m wide and the max depth is 1m. Testing equipment includes current generating

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system, wave maker, wave-height gauge, Acoustic Doppler Velocimeter (ADV), Charge-coupled Device (CCD), image acquisition system, data acquisition system, diving pump, force sensor, etc.

2.3 Test conditions

The water depth in the experiment is 0.5m whereas the corresponding actual value is 20m; Under the condition of pure current, there are two designing flow speeds V_1 = 11.1 cm/s and V_2 = 14.2cm/s with the corresponding actual values of 0.7 m/s and 0.9 m/s; Two design wave heights are 14 cm and 18 cm and the corresponding actual values are 5.6 m and 7.2 m; Test wave period is 1.2 s, 1.4 s, 1.6 s and 1.8 s, respectively and the corresponding actual wave period is 7.6s, 8.9s, 10.1s and 11.4s, respectively (The wave period is the time needed for the undulation of one wave). We determined the model scale λ=40 based on test conditions, model materials, actual sea cage size, the size of wave and flow in fish culture zones, etc. [3].

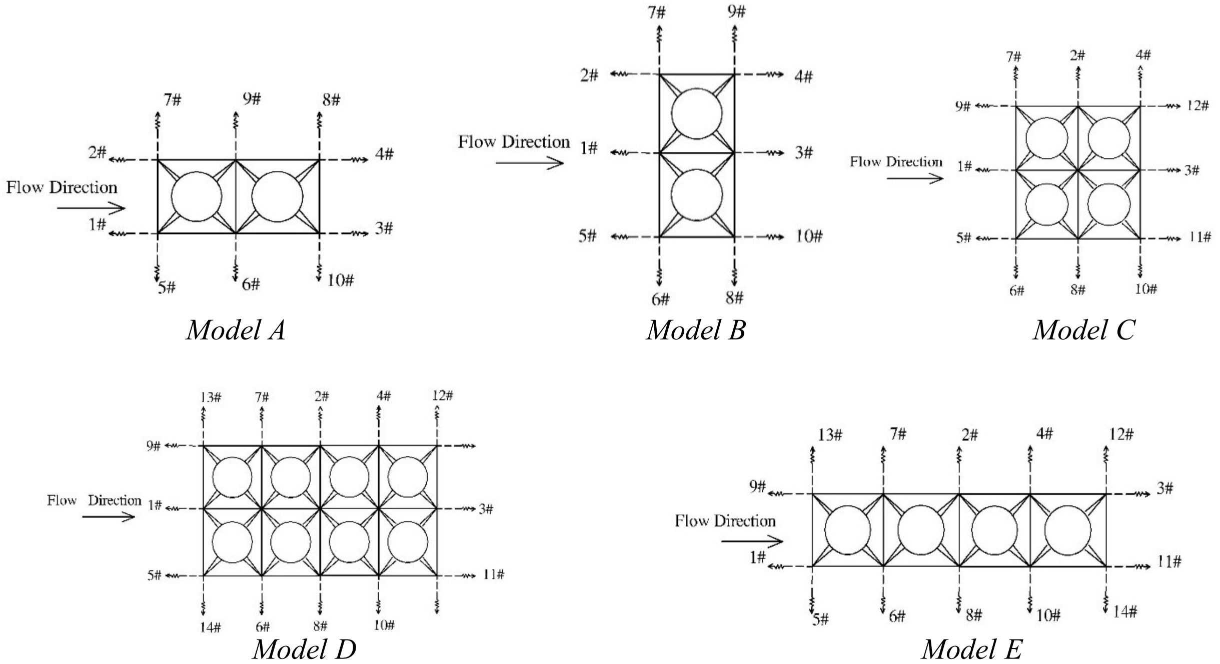

Figure 1. Composite-type sea cage combined mode.

2.4 Test model arrangement

Test arrangement [4] is shown as Fig. 2. Acoustic Doppler Velocimeter is used to determine flow velocity. It must be fixed in the harbor basin with the distance between its bottom and the bottom of the harbor basin of 0.2m. The wave-height gauge is also fixed in it in order to test the wave surface changes when the wave passes through the center of the sea cage. The force sensor should have mooring lines attached to each end and must be connected to the computer through cable harness so that it can gather the stress data from mooring lines.

3 Results and discussion

The composite-type sea cages could be separated into 3 types of arrangement, e.g., the sea cages are called tandem arrangement when they are arranged along the direction of current (model A, E), or transverse arrangement when they are arranged perpendicular to the direction of current (model B), Models C and D are called uniform arrangements. The mooring line toward the current is called the normal mooring line and its stress is a positive force. The designed 5 combined modes of sea cages are tested under pure current, pure wave and wave combined with current conditions for data acquisition and data analysis [5, 6].

There are two groups of test conditions under pure current， six groups of test conditions under pure wave, twelve groups of test conditions under wave combined with current. The normal force of each mooring line in each group must be measured three times to get the mean values and the focus should be on the maximum number of these mean values.

3.1 A study on the mooring line positive forces under pure current

Once the experiment [7] has been carried out under pure current flow and two test conditions - V1 and V2- , the results are obtained.

The positive forces and net forces described on histogram in order to get more intuitive with comparable features are shown in Fig. 3. The Arabic numerals on the horizontal axis are mooring line numbers and the numbers on the vertical axis are the corresponding positive forces and net forces.

We can see that the maximum positive force and net force on each mooring line increase with an increase in the current velocity. The max force on each mooring line is not the result of a simple addition of sea cages.

The exact figures of positive and net forces are listed in Table 1. The underlined figures in this table are the max forces of each model. By observing the max values and comparing model A with B, we have found that when the sea cages are arranged along the direction of current, the max force is bigger than that of the sea cages perpendicular to the current. By comparing the model C with E, we have found that when the sea cages are arranged along the direction of current, the max force is bigger than that on the sea cages arranged evenly along the current and perpendicular to it. With a further comparison of the model D with E, we have found that the max force has a little changed after the number of sea cages was multiplied. From the point of this angle, it is more beneficial to arrange the sea cages uniformly (model C) in the context of capital permission and in the current -based water.

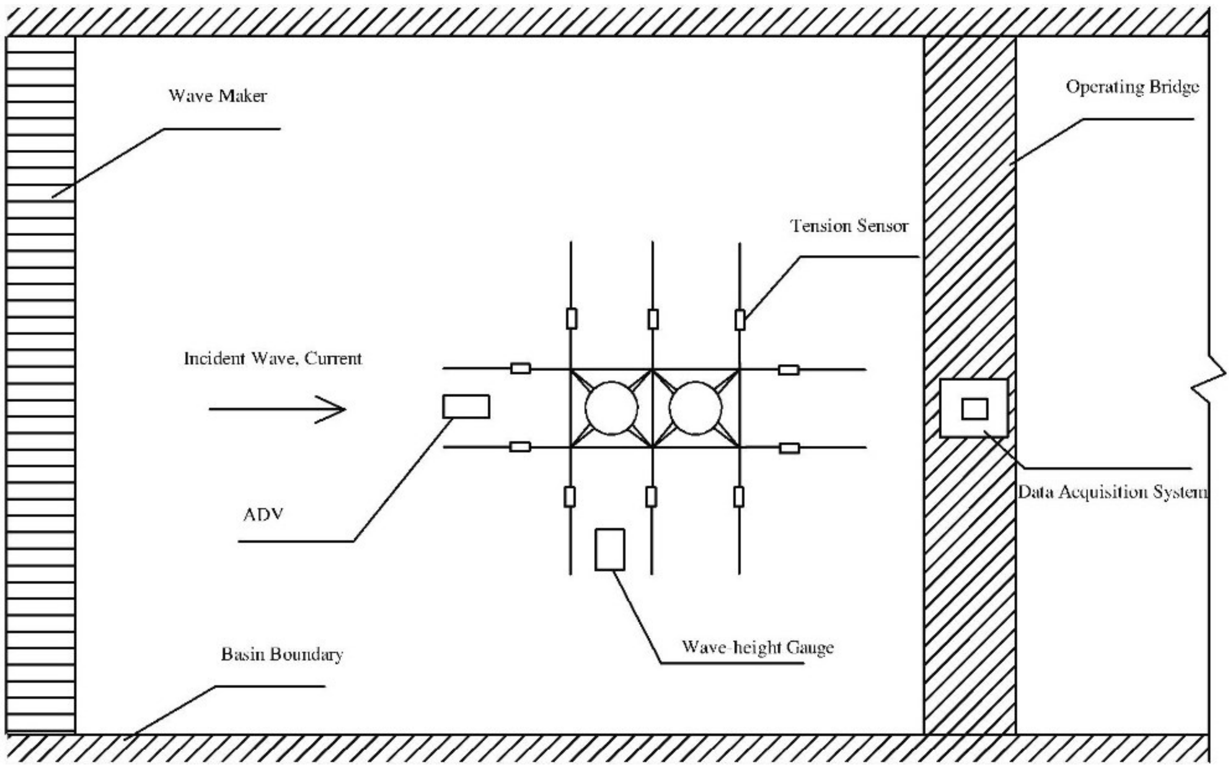

Figure 2. Test model arrangement.

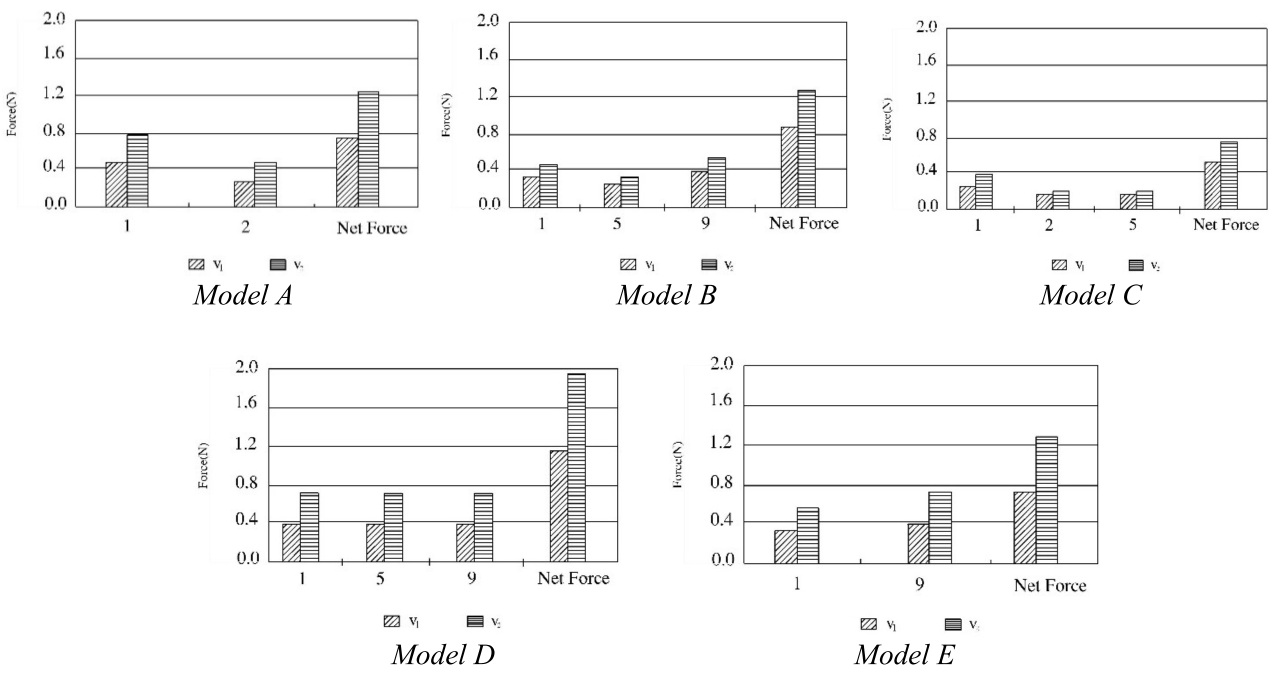

Figure 3. The forces exhibiting on current model.

Table 1. The mean positive forces under pure current (N)

Model		Model A		Model B		Model C		Model D		Model E	
Current velocity cm/s		V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
Sensor numbers	1	0.49	0.73	0.24	0.37	0.29	0.42	0.38	0.64	0.32	0.55
	2	0.27	0.49	0.14	0.20	—	—	—	—	—	—
	5	—	—	0.14	0.20	0.23	0.33	0.39	0.67	—	—
	9	—	—	—	—	0.36	0.50	0.38	0.64	0.43	0.75
Net forces N		0.76	1.22	0.52	0.77	0.88	1.25	1.15	1.95	0.75	1.30

3.2 A study on the mooring line positive forces under pure wave

There are six test conditions under pure wave [4], having each two factors: wave height and test wave period. Each maximum number of mean positive forces is taken out and listed in Table 2 after the results have been obtained and processed. The data given in the table show that model D which is arranged uniformly and has more sea cages has the maximum forces; model A which is arranged in tandem and has fewer sea cages has the minimum forces.

3.3 A study on the mooring line maximum positive forces under wave combined with current

There are twelve test conditions in this case, each having three factors: current velocity, wave height and test wave period. Each maximum number of mean positive forces is listed in Table 3[8].

From the Table, it is hard to find out the regularity of the forces acting on the mooring line. Below we analyzed the data using two aspects.

First, this paper analyzed the influences of the current velocity on the forces in the context of fixed wave height and test wave period. The calculation results are shown in Table 4. Based on the forces under V_1,

we calculate out the change rate of the forces under V_2, then the mean and amplitude change rate of forces (The maximum change rate of the force minus the minimum is the amplitude).
We can see from the table that the two values of Model A are the largest; the mean of Model C is the smallest; The mean of Model E is the second-smallest and its amplitude is the smallest.

Secondly, we consider the impact of the wave height on the forces as the current velocity and test wave period remain fixed. The calculation results are shown in Table 5. The mean value of Model B is the largest while the mean value of Model A is the smallest. The mean of Model E is the second-smallest and its amplitude is the smallest.

Table 2. The max positive forces under pure wave (N)

Wave height	Test wave period	Model A	Model B	Model C	Model D	Model E
cm	s					
14	1.2	0.227	0.231	0.263	0.377	0.302
	1.4	0.248	0.329	0.373	0.545	0.534
	1.6	0.218	0.328	0.326	0.484	0.465
18	1.4	0.265	0.498	0.557	0.762	0.691
	1.6	0.258	0.403	0.538	0.778	0.713
	1.8	0.395	0.599	0.724	0.916	0.854

Table 3. The max positive forces under wave combined with current

Current velocity	Wave height	Test wave period	Model A	Model B	Model C	Model D	Model E
cm/s	cm	s					
v_1	14	1.2	0.613	0.454	0.479	0.536	0.589
		1.4	0.561	0.557	0.621	0.728	0.768
		1.6	0.636	0.596	0.674	0.807	0.818
	18	1.4	0.655	0.658	0.733	0.884	0.862
		1.6	0.709	0.758	0.768	1.085	1.025
		1.8	0.992	1.011	0.974	1.248	1.234
v_2	14	1.2	1.049	0.599	0.560	0.794	0.812
		1.4	0.909	0.764	0.728	1.030	1.038
		1.6	0.911	0.740	0.730	1.130	1.040
	18	1.4	0.967	0.976	0.880	1.257	1.121
		1.6	1.040	1.097	0.975	1.424	1.224
		1.8	1.269	1.274	1.177	1.739	1.502

Table 4. The variation forces caused by the current velocity under wave combined with current (%)

Sea cage model	Model A	Model B	Model C	Model D	Model E
The mean change rate of forces	49.7	35	11.2	40.4	29.4
The amplitude change rate of forces	43.1	22.3	20.7	18.9	18.5

This research proves that the sea cages could be arranged in tandem (model E) in the waters under wave combined with the current.

3.4 The impacts of cage numbers on the characteristics of the mooring line force

Based on the test data of Tables 1,2,3, the variation of the forces has been compared in the case of the same arrangements and a different number of sea cages. The change rate of the forces acting on model E, D compared with model A, C, respectively is figured out benchmarked against the forces acting on model A, C. The results are shown in Table 6. Comparing the two models E with A which are both arranged in tandem, we have found that the added forces are very small under pure current and wave combined with current and they are the largest under pure wave. This illustrates that the number of sea cages arranged in tandem should be less under pure wave and should be more under pure current and wave combined with current. Comparing the two models D with C which are both arranged uniformly, we have found that the mean change rate of forces is all small and relatively close to each other. The minimum mean change rate of forces that is 30.4%, occurs in pure current. The above evidence strongly suggested that the number of sea cages arranged uniformly may properly increase under pure current.

4 Conclusion

Combined with practical situation on site, three conclusions were given by analyzing the 5 working models under pure current, pure wave and both combined.

First, we can choose a reasonable number of sea cages and uniform arrangement at the current-based sea area (model C).

Second, we can choose a little bit smaller number of sea cages and tandem arrangement at the wave-based sea area (Model A).

Third, we can choose a little bit larger number of sea cages and tandem arrangement at the wave combined with current sea area (Model E).

Acknowledgment

We kindly acknowledge financial support by the science and technology research project of Hebei colleges and universities (No Z2011315).

The author is also very grateful for the support provided by science and engineering foundation key project of Hebei Agricultural University (No ZD201409).

Table 5. The variation forces caused by the wave height under wave combined with current (%)

Sea cage model	Model A	Model B	Model C	Model D	Model E
The mean change rate of forces	12.2	30.3	21.6	26	20.3
The amplitude change rate of forces	10.9	30.1	15.6	13	7.9

Table 6. The impacts of cage numbers on the characteristics of the mooring line force (%)

	E/A		D/C	
	The mean change rate of forces	The amplitude change rate of forces	The mean change rate of forces	The amplitude change rate of forces
pure current	4.73	-12.2～2.74	30.4	20.6～34
pure current	119.2	33～176	36.2	26.5～48.5
wave combined with current	18.3	-22.6～44.6	34.5	11.9～54.8

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