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Comparisons on the Mooring Line Force and Cage Motion Characteristics of Gravity and Sea Station Cages

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ABSTRACT

This paper gives the comparisons on the force and movement characteristics of different cage models. Three models were selected including one Gravity Cage, one Sea Station Cage and one Quasi-Sea Station Cage. The Sea Station Cage model has equivalent enclosed volume with Gravity Cage model but is bigger in cage diameter and height. The Quasi-Sea Station Cage model is of the same diameter with the Sea Station Cage model but is 1.4 times in cage height. This increases its effective aquaculture volume up to 2.2 times that of the latter one. This model test was carried out under floating and submerged conditions. Pure current, pure wave and wave combined with current conditions were set during the test. The force data were measured by the transducers attached to the bottom of each mooring line. Cage movements were analyzed by tracing the diodes fixed on the floating system or the rigid ring. Results show that current-induced loads depend on the cage style greatly but turn out to be relatively weak under wave conditions. Submergence of cages decreases the loads and movement range, especially under wave conditions. Comparisons on mooring line forces and cage movements are also made between different cage models and some conclusions on the selection of cage style were drawn.

KEY WORDS: Gravity Cage; Sea Station Cage; mooring line; force characteristics; motion characteristics

INTRODUCTION

Deep water sea cages are important facilities for marine aquaculture. Many cages of different styles were designed and applied quickly in recent years. The Gravity and Sea Station Cages are used quite popular (Gui et al. 2002). Scholars from many countries made their efforts in this field, but the results are quite different. Colbourne (2001) studied the force and movement characteristics of Gravity Cages with several kinds of weighting and mooring styles and pointed out that wave action is not a significant contributor to the mooring line loads while the tidal current is the most likely environmental excitation. In North America, Sea Station Cages are recommended. Loverich & Gace (1997) once made comparisons on several classes of sea cages and drew the conclusion that Sea Station Cage is the most suitable style for open sea aquaculture. Fredriksson (2001), in his Doctorial dissertation, did many researches on Gravity and Sea Station Cages and several conclusions were drawn. Li (2003, 2004) also focused their researches on the force and movement characteristics of Sea Station and Quasi-Sea Station Cages and several useful results were achieved. Zhang (2002) gave a numerical method for calculating the wave forces acting on Sea Station Cage. This paper focuses on the general study of mooring line force characteristics and cage movement of Gravity, Sea Station and Quasi-Sea Station Cages under pure current, pure wave and wave combined with current conditions. The results will give some guidance for the selection of cage style.

MODEL AND EXPERIMENTAL CONDITIONS

Floating and submerged performance are two common conditions for sea cages during marine fish aquaculture. In general, the sea cage is kept floating, which is convenient for daily management, and submerged to avoid severe wave attacking. Under both conditions, the sea cages have to endure the loads induced by tidal current or waves or both of them. Model tests are the important way to know the force and motion characteristics of cages. Pure current, pure wave and wave combined with current conditions were set during this experiment. The hydrodynamic characteristics of sea cages under both floating and submerged conditions were studied. Table 1 shows the model setting in detail.

Table 1 Model test conditions

Models	Cage style	Diameter /(m)	Height /(m)	Volume /(m^3)	Weight/(N)	Weight style	Submerging methods
I	Gravity	0.637	0.4	0.127	3.92	Sinker	Two pipe perfusion
II	Sea Station	1.0	0.5	0.131	2.26	Ballast	Center spar perfusion
III	Quasi-Sea Station	1.0	0.7	0.288	2.26	Ballast	Center spar perfusion

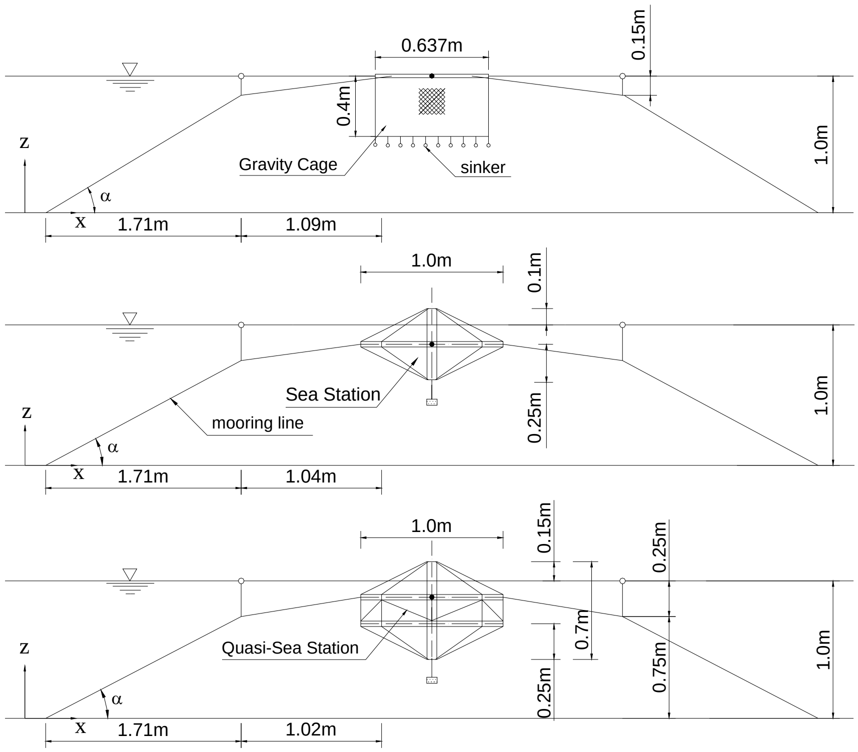


Fig.1 Sketch of cage models under floating condition
(Black dots on cages are the tracing points)

Fig. 1 is the model setting of different cages under floating conditions. All cage models were moved to 2/5 of the water depth when submerged. The mooring line forces were acquired by the transducers attached to the bottom of each mooring line. Cage movement data were gathered by tracing the diodes fixed on the rigid ring or floating system of each cage model by CCD camera.

EXPERIMENT RESULTS AND ANALYSIS

Force Comparison Under Pure Current Conditions

The cage models were set symmetrically in both transverse and longitudinal directions. For analysis, forces in the two mooring lines at the same side (wave side or lee side) were superposed to avoid the unsynchronization of mooring line forces because the currents or waves may not be uniform in the whole field. Figs. 2~3 show the current induced loads and the corresponding experiment conditions (where F denotes floating; U denotes submerged; Model I~III means Gravity Cage, Sea Station and Quasi-Sea Station Cage models respectively).

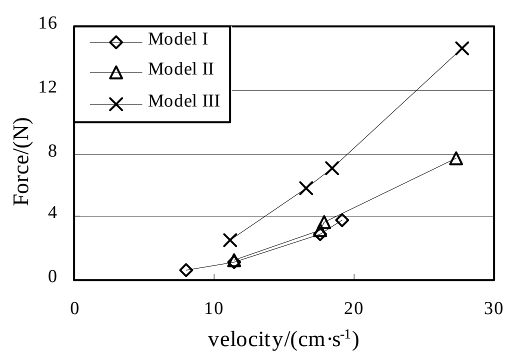


Fig.2 Comparison on mooring line forces of each model under floating condition

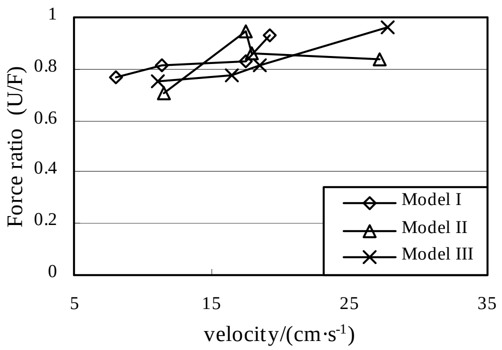


Fig.3 Comparison on mooring line forces under floating and submerged condition

As shown in Fig. 2, the mooring line forces of Quasi-Sea Station Cage are apparently larger than those of the other two cage models because of its special structure and cage size. The mooring line forces of Gravity Cage are similar to those of Sea Station Cage under each current condition. One may suppose that the mooring line forces will not change obviously when the models are submerged, but results show that they had 5%~30% decrease, as shown in Fig. 3. The attenuation of the current velocity in water depth direction and that models are easier to incline under submerged condition may be the important reasons for the force reducing.

Force Comparison Under Pure Wave Conditions

In the open sea, waves are the most common environmental loads acting on sea cages. Experiments were also carried out under different wave conditions. The forces in time series show that the values in wave side mooring lines are always larger than those in the leeward mooring lines. Therefore, we superpose the forces in the two wave side mooring lines and make comparisons on the maximum forces.

As shown in Fig. 4, wave-induced forces on Gravity Cage are relatively smaller than those on the other two cage models. The mooring line forces increase as the wave height increases, but seem to have no apparent relationship with wave period, namely, the maximum force will occur at a certain wave period. As for the other two cages, they seem to be of similar force characteristics. But in general, the mooring line forces decrease as the wave period becomes longer. The mooring line forces of each model decrease sharply when it is submerged and that is more obvious as the waves get higher. The maximum force reduction reaches to nearly 80% under extreme wave condition. Comparisons within the three cage models reveal that Gravity Cage has a relative better performance from the viewpoint of forces.

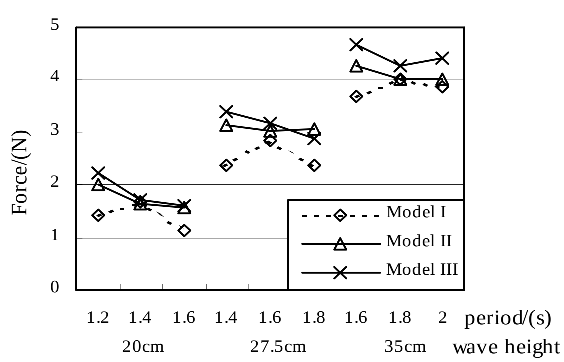


Fig.4 Comparison on mooring line forces of each model under floating condition

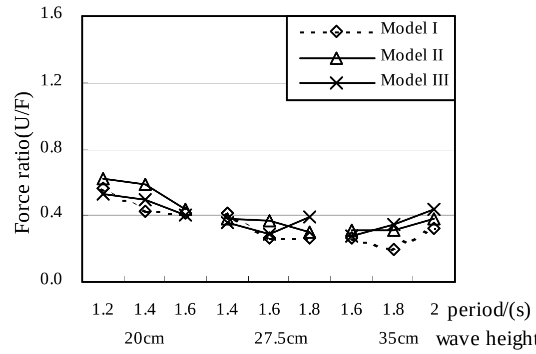


Fig.5 Comparison on mooring line forces under floating and submerged condition

Force Comparison Under Wave Combined With Current Conditions

During this experiment, two kinds of current (S1=11.54cm/s and S2=17.29cm/s) were selected to combine with different waves respectively. The current direction was the same as the direction of wave propagation. Waves were produced after the currents got steady in the tank. The results are shown in Figs. 6~9.

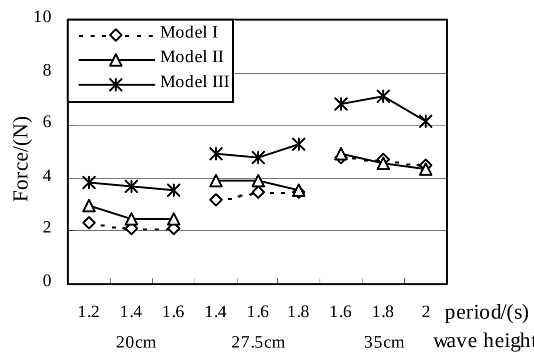


Fig.6 Comparison on mooring line forces of each model under floating condition with current velocity S1=11.54cm/s

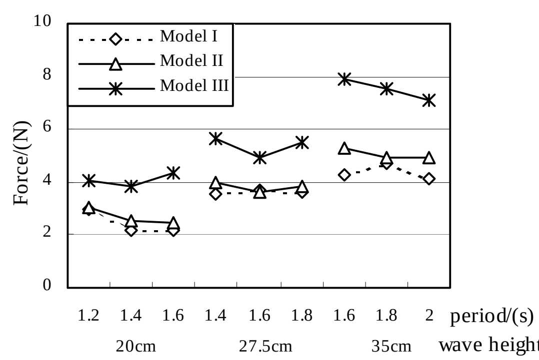


Fig.7 Comparison on mooring line forces of each model under floating condition with current velocity S2=17.29cm/s

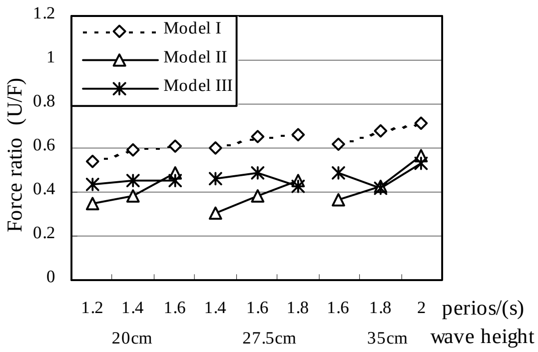


Fig.8 Comparison on mooring line forces ratio after submerged with current velocity S1=11.54cm/s

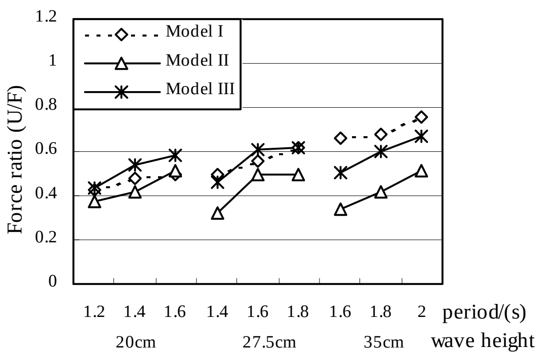


Fig.9 Comparison on mooring line forces ratio after submerged with current velocity S2=17.29cm/s

The mooring line forces of the Quasi-Sea Station Cage are obviously bigger than those of other two cages because of its special structure style and cage size. The Gravity and Sea Station Cages turn out to be of similar force characteristics. As shown in Figs. 6~7, there is no apparent difference of the mooring line forces for the Gravity and Sea Station Cages as the current velocity increases. The wave forces seem to dominate the response for the floating cage under wave combined with current conditions.

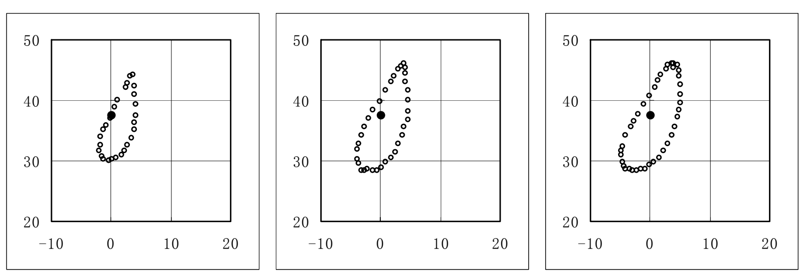
The forces decrease when the models are submerged. The force reduction rates, when compared to those under pure wave conditions (see Fig.5), exhibit an opposite trend of variation. They become less as the waves get higher, see Figs. 8~9. From Figs. 8~9, we can draw a conclusion that Sea Station Cage seems to have better performance under wave combined with current conditions for the larger attenuation of mooring line forces.

CAGE MOTION

The cage movement will affect the living condition of fishes in cage greatly. It is important to get knowledge of the motion characteristics of each kind of the sea cages. During this experiment, the motion trajectory of the tracing points fixed on the floating system (Gravity Cage) or rigid rings (Sea station and Quasi-Sea Station Cages) was studied by analyzing serials of pictures acquired with CCD camera. The results are abundant and cannot be listed completely. Here, we only discuss the results of the motion trajectory and the inclination angle in time series under pure wave conditions with wave height of 20cm and wave periods of 1.2s, 1.4s and 1.6s respectively.

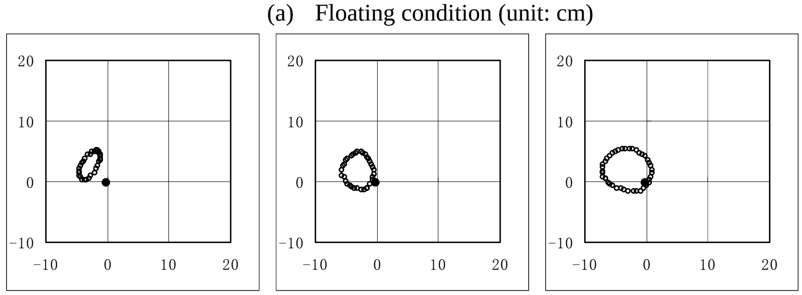
Motion Trajectory

Motion trajectory results are given in Figs. 10~12. The black dots are the static position of the tracing points. Results show that the motion trajectory of the tracing point has apparent relationship with wave periods. As for the Gravity Cage, the amplitude in vertical direction is bigger than that of the other two cage models, especially under floating condition. But the difference looks to be relative small in the horizontal direction.



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

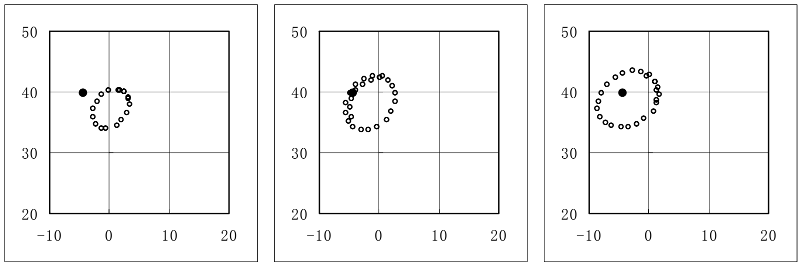
(a) Floating condition (unit: cm)



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

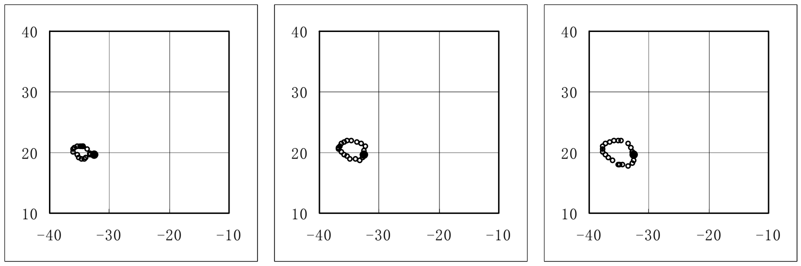
(b) Submerged condition (unit: cm)

Fig.10 Motion trajectory of the tracing point on the floating system of Gravity Cage



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

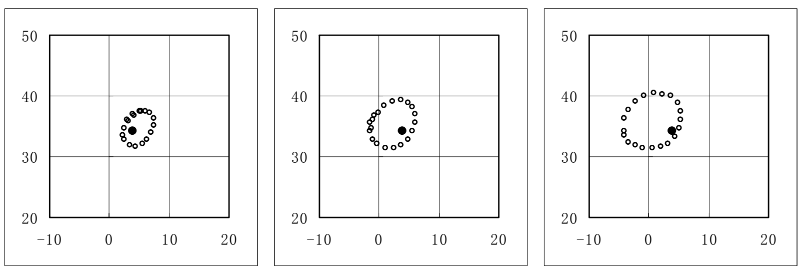
(a) Floating condition (unit: cm)



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

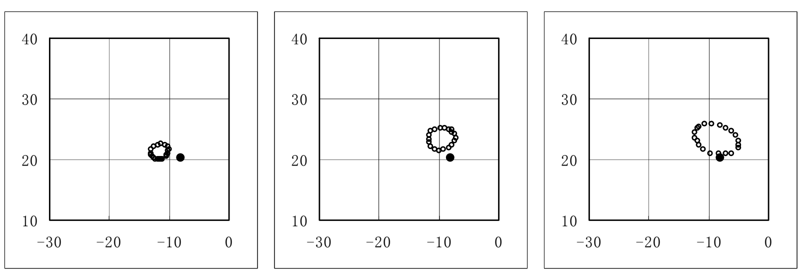
(b) Submerged condition (unit: cm)

Fig.11 Motion trajectory of the tracing point on the ring of Sea Station Cage



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

(a) Floating condition (unit: cm)



H=20cm T=1.2s H=20cm T=1.4s H=20cm T=1.6s

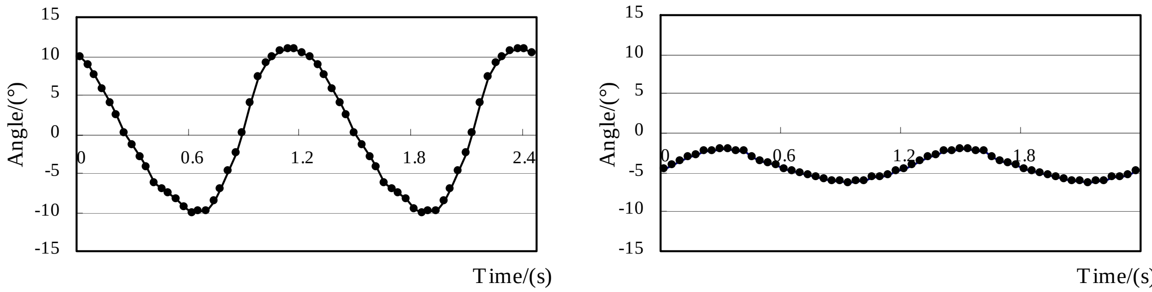
(b) Submerged condition (unit: cm)

Fig.12 Motion trajectory of the tracing point on the ring of Quasi-Sea Station Cage

Inclination Angle of The Floating System or Rigid Ring Under Pure Wave Condition

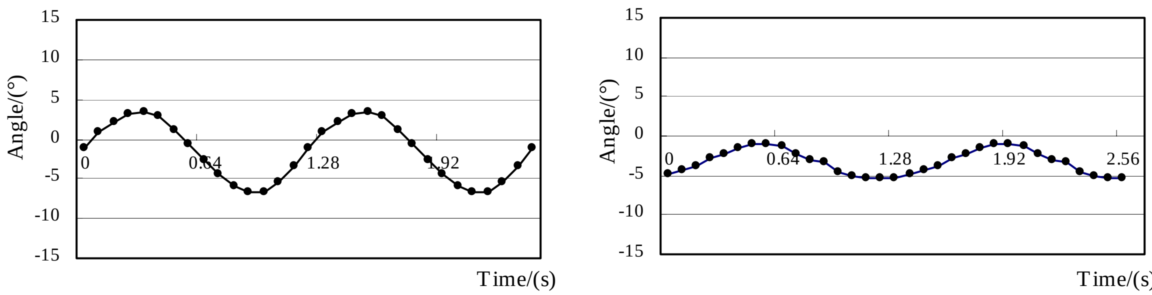
By tracing the two diodes fixed on the floating system or rigid rings at the fore and back cleat points at the same time, we can get the variation of the inclination angle in time series. Figs. 13~15 are the results of different three cage models under the pure wave condition with wave height and period of 20cm and 1.2s. It is easy to find that the maximum inclination angle of Gravity Cage is nearly 2 times that of the Sea station and Quasi-Sea Station Cages under floating condition. When the cage models are submerged, the inclination angle of each model decreased obviously, especially for the Quasi-Sea Station Cage.

Based on this analysis of motion trajectory and inclination angle, we can draw a conclusion that Sea Station and Quasi-Sea Station Cages are more stable than Gravity Cage under pure wave conditions. That is because the floating system of the Gravity Cage is on the water level and will move with the wave motion. Since the rigid ring of the Sea station or Quasi-Sea Station Cage is always under water surface, the amplitude of the motion and inclination angle will reasonably reduced.



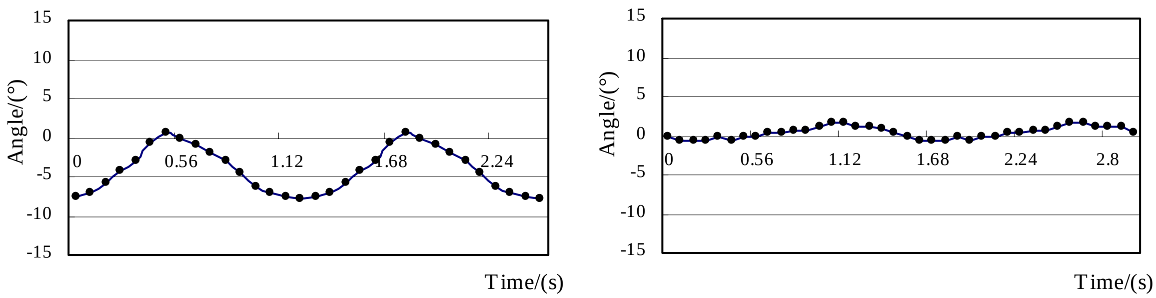
(a) Floating (b) Submerged

Fig.13 Inclination angle variation of the floating system of Gravity Cage



(a) Floating (b) Submerged

Fig.14 Inclination angle variation of the ring of Sea Station cage



(a) Floating (b) Submerged

Fig.15 Inclination angle variation of the ring of Quasi-Sea Station cage

GENERAL COMPARISONS

Cages with different styles will exhibit different force and motion characteristics under the same current and wave conditions. As an offshore aquaculture facility, the security, management and investment et al. are the main factors to be considered. Table 2 is the general comparisons of each cage model under floating and submerged conditions. Here, we selected Gravity Cage as reference. The values of mooring line forces, aquaculture volume and price et al. are all set to 1.0, under which are the ratios of comparative values of the other two cages.
From the viewpoint of forces, the Gravity Cage has the advantages when it is affixed with heavier sinkers. The management of Gravity Cage is more convenient and the investment is much lower comparing with the other two cages. The Sea Station and Quasi-Sea Station Cages are of semi-rigid cages, which benefit the controlling of volume reduction and the prevention from predators. But the maximum volume of the Gravity Cage is nearly 3 times that of the Sea Station Cage, given the same size of cage diameter and height. In other words, the advantages of Sea Station Cage are acquired by losing largely the original aquaculture volume. Even with the same original volume as Gravity Cage, the management of Sea Station and Quasi-Sea Station Cages is inconvenient. From the viewpoint of cage motion, the Sea Station and Quasi-Sea Station Cages exhibit better stability, which is considered profitable to fishes in cages. But we should keep in mind that even the cages can endure the action of tidal current or waves, we cannot make sure whether the fishes in cages can survive.

Table 2 General comparisons of each cage model under floating and submerged conditions (ratios)

Status	Cage Model	Pure Current (cm/s)			Pure wave (H=35cm)			Wave & Current*			Diameter	Volume	Prices
		11.5	15.5	17.2	T=1.6s	T=1.8s	T=2.0s	T=1.6s	T=1.8s	T=2.0s			
Floating	I	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	II	0.97	1.02	1.04	1.16	1.0	1.04	1.24	1.04	1.18	1.57	1.03	3～4
	III	2.11	2.08	2.06	1.27	1.06	1.14	1.84	1.58	1.71	1.57	2.27	>4
Submerged	I	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	II	0.84	1.12	1.11	1.43	1.63	1.16	0.64	0.63	0.81	1.57	1.03	3～4
	III	1.96	1.92	1.9	1.4	1.97	1.5	1.41	1.4	1.51	1.57	2.27	>4

Note: * Here, wave height H=35cm and current velocity S2=17.29cm/s.

CONCLUSIONS

This paper gives the comparisons on the force and movement characteristics of Gravity, Sea Station and Quasi-Sea Station Cages. The results will benefit the selection of cage style.

In general, the selection of cage style depends on the field conditions. Gravity Cage has apparent advantages in sea areas with good shelter. But in the open sea, tidal current and waves may become very severe, Sea Station and Quasi-Sea Station Cages are the ones for considering, but its security and the capability of the fishes to endure the current or waves should also be considered.

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